1. AIMS AND BACKGROUND

1.1 Following concern and subsequent industrial action by the National Union of Seamen (NUS) the annual UK dumping of solid radioactive waste in the Northeast Atlantic was suspended in 1983 and the Government and the TUC together agreed that an independent review of evidence regarding the safety of dumping was required. The Secretary of State for the Environment, the Rt Hon Patrick Jenkin MP, requested Professor F G T Holliday to chair the review in which three others participated. The Secretariat was provided by the Institute of Oceanographic Sciences (IOS) and the Department of the Environment (DOE). (Participants are listed in the Appendix.)

1.2 The terms of reference were:– "to review the scientific evidence, including the environmental implications, relevant to the safety of disposal of radioactive waste at the designated North Atlantic site, and to make a report to the Secretary of State for the Environment, the Minister of Agriculture, Fisheries and Food, and the Trades Union Congress".

1.3 For over 30 years the UK has been disposing of radioactive waste into the oceans, either as low-level liquid waste into coastal waters, as at Sellafield and nuclear power stations, or as packaged waste into international waters.

1.4 All the material dumped at the Northeast Atlantic dumpsite is first sorted, packed and encased in concrete in specially designed steel containers (see sections on packaging in Chapter 3), loaded aboard ship and, under close inspection and control, transported to the dumpsite and dropped over the side as the ship steams slowly along.

1.5 Greenpeace has objected to sea dumping over a number of years and during the dumping cruise in August 1982, the dumping ship GEM was closely followed by the Greenpeace ship SIRIUS. Despite a legal injunction not to interfere with the operation, members of the Greenpeace organisation came alongside in small inflatable boats, boarded the GEM and sought to prevent the drums being discharged. It was a hazardous venture; it delayed the dumping operation, was widely reported by newspapers and television and caused great disquiet to all concerned.

1.6 No matter what the rights and wrongs of a situation, the instinct of most seamen is to avoid putting the safety of other seamen at risk. It was no surprise to us to learn from the General Secretary of the NUS that it was such a feeling and the conflicts it engendered that led, in the first place, to the Union expressing concern.

1.7 As a result the NUS were led to consider the wider apsects of dumping, and although not by any means unanimous on what is a very complicated matter, they were reinforced in the view that their concern was justified by the vote taken at the February 1983 meeting of the London Dumping Convention, LDC (see section 3.3), when a proposal to prohibit dumping was not passed but a resolution calling for a voluntary suspension until the completion of an LDC scientific review was accepted by the majority of participating states. A vote at the LDC is an unusual occurrence.

1.8 The UK delegation opposed the suspension on the grounds that it was not based on sound scientific and technical evidence as required by the Convention. At the same time the delegation indicated that the LDC review should go ahead and, if the findings were that dumping posed a scientifically significant risk to human health or to the marine environment, the UK would stop dumping at sea.

1.9 The NUS did not feel in a position to appraise the detailed, complicated and apparently contradictory evidence, so took its stand on the fact that the UK was a party to the Convention and should accept the voluntary suspension agreed by the majority. The seamen's action was subsequently supported by other transport unions and the dumping operation planned for July 1983 had to be postponed.

1.10 The Trades Union Congress, in September 1983, endorsed the transport unions' action. In the light of the ensuing complicated impasse, the Government and TUC together agreed in December 1983 on the need for an independent review of the safety of UK dumping – that is the present review. The plans to dump waste in 1983 were abandoned.

1.11 It was against this background that we started work in April 1984. Our terms of reference were deliberately drawn to include a review of 'environmental implications' as part of the scientific evidence. This term has a wider meaning than that sometimes given to it by individuals trained only in the earth and biological sciences, and includes social, economic, legal and political considerations. We therefore felt a need to look at these wider implications and they have been given substantial importance in deriving our conclusions. The alternatives to sea dumping were also considered.

1.12 At the first meeting on 27 April 1984 we began our work by adopting a question and answer approach. Each member compiled a list of questions relating to the issues. These lists were submitted to the scientific secretariat for sorting and for seeking answers from known sources or, where appropriate, from the responsible authority. Individual unions were also invited to submit questions. Inevitably this procedure led to further questions. It is not practical to list and give answers to all the questions which were posed, but many were of a similar nature and could be combined into general categories which form the basis of the descriptive text which follows. We were unable to find answers to all the questions asked.

1.13 We recognised that the major part of our task involved the reading of a vast quantity of literature and therefore felt it inappropriate and impractical to undertake a widespread public consultation exercise. However, we agreed that, although we had access to much of the scientific work, there was a need to seek unpublished scientific work and published work which was not readily accessible. Our Chairman therefore wrote to selected organisations and advertisements requesting relevant submissions were placed in the journals Nature, New Scientist and New Society.

1.14 Some consideration needed to be given as to why other countries were not presently dumping radioactive waste at sea and we decided that some assessment of radioactive waste management policy abroad particularly in France, Federal Republic of Germany and the Netherlands, might prove helpful. We were also interested to know more about the Japanese assessment of proposed sea dumping in the Pacific.

1.15 Two visits were made during our deliberations, one to the Atomic Energy Research Establishment (AERE), Harwell, to see the sorting and packaging plants for radioactive waste operated by the United Kingdom Atomic Energy Authority (UKAEA) and to have discussions with the UKAEA and the Nuclear Industry Radioactive Waste Executive (NIREX). The other was to the Fisheries Laboratory of the Ministry of Agriculture, Fisheries and Food (MAFF), Lowestoft, where we were given a presentation by MAFF scientists and staff of the National Radiological Protection Board (NRPB). The Chairman also saw waste management arrangements at British Nuclear Fuels plc (BNFL), Sellafield.

1.16 Written submissions and oral evidence were received from a number of individuals and from representatives of government and other interested organisations. (These are included in the Appendix.) Each member of the committee sought help from colleagues, and some commissioned work from other organisations. We would like to thank all these people for their interest and in particular we would like to thank DOE, MAFF and AERE for their hospitality and for answering a large number of queries.

1.17 Chapters 1–6 in this report are a condensation of the facts as we see them. In the final chapters, we discuss acceptability of sea dumping, draw conclusions and make recommendations. We have included a short glossary to avoid lengthy definitions in the text. Words which appear in the glossary are written in italics when first mentioned in the text.

1.18 The committee was most fortunate in having the services of Dr D Smythe-Wright and Dr S Thorpe of the IOS and Mr S Benton of DOE as the Secretariat. Their help and guidance on technical matters, their patience in recording our views and conclusions and their arrangements for our meetings and travel made our task much easier. Whilst they helped to clarify the facts and views in this report, the responsibility for them rests with members of the team and not the Secretariat.

2. THE NATURE OF THE PROBLEM

What is pollution?

2.1 Pollution is the introduction by man of substances or energy to the environment resulting in deleterious effects such as hazards to human health, harm to living resources, hindrance of activities and reduction of amenities; environmental safety includes all these aspects. In assessing pollution it is therefore necessary to discover the effects of a particular input, decide whether or not they are deleterious and, if so, in what way and by how much.

2.2 If the deleterious effects are sufficiently great to warrant remedial action, then a number of provisos need to be borne in mind. It is only too easy, when considering pollution in isolation, to recommend remedies that merely transfer a problem to a different environment where the impact may be even greater. Given that wastes are inevitably generated by all human societies, and disposal of them may cause some local environmental impairment, the best solution is that which causes least, or the most acceptable, environmental damage. Economic considerations are also important; in the words of Lord Flowers 'We do not want a billion pound solution to a million pound problem'.

2.3 Many wastes discharged to the sea are *biodegradable* and are rapidly broken down to harmless constituents, others are long lasting or essentially permanent additions to the sea. Of these, some are entirely man-made and do not otherwise occur in nature whilst others are natural constituents of seawater. Most radioactivity is natural but some *radionuclides*, for example plutonium-241 and americium-241 are man-made. Whilst radioactive waste has some features in common with other marine waste there are also some differences (see sections 2.23—2.24).

What is radiation?

2.4 Everything is made up of atoms, each one is composed of a nucleus, which contains almost the entire weight of the atom, surrounded by negatively charged particles called electrons. The two principal particles in the nucleus are the positively charged proton, and the neutron. The neutron weighs the same as the proton but has no charge.

2.5 The number of protons in the nucleus (known as the atomic number) is fixed and characteristic of a particular chemical element, but the atoms of an element may have different numbers of neutrons in the nucleus.

2.6 As the atomic number increases the number of neutrons increasingly exceeds the number of protons, and the nuclei become unstable and disintegrate in order to achieve stability. During disintegration the nuclei may emit the following variety of radiation.

2.7 **Alpha particles**: these are positively charged particles containing two neutrons and two protons. They are emitted at high speed from the nucleus, they do not travel very far and are easily stopped. They cannot penetrate the skin or a piece of paper. However, if alpha emitters are breathed in or swallowed, and remain in the body they can be very harmful.

2.8 **Beta particles:** these are high energy negatively charged electrons. They are much smaller and lighter than alpha particles and travel faster. Whilst they can pass through the skin and penetrate the body they can be stopped by a fairly thin sheet of lead or aluminium.

2.9 **Gamma rays:** during the emission of alpha and beta particles, it is possible that some nuclei may also get rid of another form of surplus energy. When this occurs the excess energy is emitted as a gamma ray. These rays are similar to radio waves or to visible light, but they have a much shorter wavelength. Gamma rays are extremely powerful and penetrating. They travel very fast and are able to pass right through the body. Thick sheets of lead, many feet of concrete or water are required to stop them.

2.10 The process by which atoms emit alpha and beta particles and gamma rays is called radioactive decay and the energy emitted, in any of the forms listed above is collectively known as ionizing radiation.

2.11 Radiation is the transfer of energy through space, air or some other medium. A good example of such a transfer of energy is heat from a fire, in which the energy from the burning of fuel is felt as warmth to those sitting in front of the fire without the temperature of the intervening air being significantly raised. The fire will burn you if you move closer to it, you do not have to touch it and the hotter the fire the greater the effect.

2.12 About 87% of the radiation to which the population of the UK is exposed comes from natural sources. Radioactive uranium and thorium are found in the earth; some radiation comes from *cosmic rays* in space; and some radioactive gases are produced in the atmosphere by the sun. The remaining 13% is man-made resulting from the treatment of cancer and medical diagnosis (11.4%), fallout from atmospheric weapon testing in 1950s and 1960s (0.5%) and routine power plant operations and uses in scientific research, defence and industry (1.1%).

Radioactive half-life

2.13 The decay of a radioactive element occurs at a rate proportional to the number of atoms; it cannot be told at what time any particular atom of an element will decay. What is certain is the period over which half of the material will have decayed, called the half-life. For example, starting with a gram of radium-226, half a gram will be left in 1600 years (that is, its half-life), a quarter of a gram in 3200 (2 x 1,600) years, and an eighth of a gram in 4800 (3 x 1,600) years. The radium will be decaying to its 'daughter products', ie other elements of lower atomic mass, many of which are also radioactive.

Radioactivity in the sea

2.14 Most chemical elements exist in radioactive and stable forms and, albeit at a low level, the sea is naturally radioactive and contains alpha, beta and gamma emitters. Most of the activity is due to the *long-lived* radionuclide potassium-40 (half-life 1.3×10^9 years). *Short-lived* nuclides, formed by collision of cosmic rays with atoms in the atmosphere, are also present in sea water, notably tritium (half-life 12.4 years). The total natural background radioactivity is about 0.013 *Bq* (Becquerel) per cubic metre. Deep sea sediments are also naturally radioactive with levels between 5×10^2 and 2×10^4 Bq per kilogram. This background activity in the sea has been augmented globally by fallout from the tests of nuclear weapons in the atmosphere and locally by dumping or by coastal discharges of waste (as from Sellafield). These artificial components are similar in kind to naturally occurring radioactivity and have so far added about 0.6% and 0.005% respectively to the overall background radioactivity of the oceans.

2.15 The physical characteristics of the elements differ in that some, for example, iodine, caesium and tritium, are very soluble in seawater and become diluted and widely distributed in water currents, whilst others, for example, plutonium and americium, tend to become attached to sediment particles and incorporated into the sea bed.

Hazards of radioactivity

2.16 All radioactivity is potentially damaging to living matter but its effects depend among other things on the following:

- ★ the activity of the source
- ★ how close it is
- ★ how well shielded
- ★ the length of time exposed to it
- ★ the type of radiation
- ★ the tissue irradiated.

2.17 Natural radiation levels vary and we all come into contact with some form of artificial radioactivity in our lives. For example a television set gives out radiation from the tube, but the source is so small that you would have to stand very close to it for a very long time to receive even a trivial additional *dose*.

2.18 The International Commission on Radiological Protection (ICRP) is formed from recognised experts on the effects of radiation on man and is a source of guidance on radiological protection. It has estimated that the biological effect from an ingested alpha particle is a factor of twenty-times greater than the effect of an equivalent amount of radiation in the beta or gamma form. This is taken into account in NRPB's assessments (see Chapter 5).

2.19 Direct exposure to a very powerful source of radiation can have rapid effects and in very extreme cases such as nuclear war it can kill on the spot. The most important effects of radiation are:

- ★ fatal and non-fatal cancers
- ★ a range of heriditary effects.

However in this review we are concerned with the doses which result from continued low-level exposure over an extended period of time.

2.20 It is difficult to identify radiation damage with any certainty unless it is on such a massive scale as to be obvious. This is because:

- ★ there is not a simple relationship between the dose of radiation received and the development of symptoms of radiation damage

- ★ there is usually a long delay between exposure to radiation and the development of symptoms

- ★ the symptoms occur naturally in the absence of radiation or may be caused by non-radioactive substances.

Identification of damage caused by radioactive discharges therefore depends on establishing that these pathological conditions are more common in exposed populations than would otherwise be expected, and that the excess number of cases is due to radiation damage and not something else.

2.21 If radioactive material is present in water or food, the effects can be passed on to humans through the food chain. Radiation is not infectious, it cannot be 'caught' from others who have been exposed.

Transfer mechanisms from the sea to man

2.22 Radioactive elements behave chemically in the same way as their stable counterparts and can accumulate in certain organs of the body instead of being generally distributed, for example radioactive iodine in the thyroid gland and strontium (which behaves like calcium) in bones. In the sea, seaweeds and *bivalve molluscs*, such as mussels, are able to acquire very large concentrations of particular elements from the surrounding seawater, but there is wide variation in the elements preferentially accumulated even in closely related species. Radioactive forms of these elements present in the seawater are accumulated proportionately and the organisms become radioactive as a result. *Crustacea* and fish, on the other hand are mostly non-accumulators and by excreting the excess are able to regulate the concentration of elements in their body.

2.23 Generally, for pollution of the sea, the health hazard is through the contamination of seafood. Harmful effects from radioactivity depend, in a similar way to heavy metal pollution, more on the total dose received over a period of time than on the degree of contamination of a single sample of seafood. Human exposure to the damaging agent therefore depends on dietary habit as much as on the degree of contamination of various items of seafood eaten. Because some of these substances also occur naturally in food they obviously cannot be banned; protection of human health can only be ensured by setting an agreed limit to the contamination of marine products used for human food. The limit is set to reduce the threat to human health to a very low level. It is also necessary to identify groups of people that may be particularly exposed as a result of occupation or dietary habits.

2.24 Radioactivity may also threaten human health by:

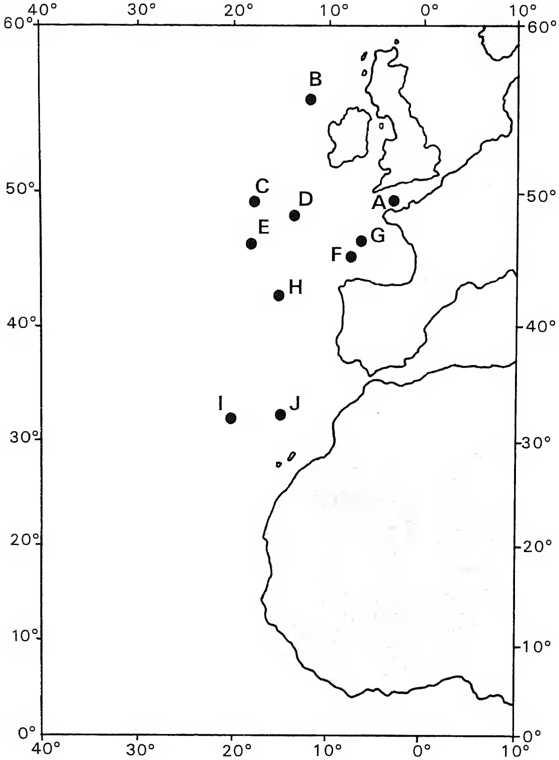
- ★ direct external exposure, for example with contaminated material cast ashore on the beach

- ★ the inhalation of contaminated wind borne sea spray or dust particles.

Standards for radiation exposure to man

2.25 The dose limits recommended by ICRP, and endorsed for UK use by NRPB, reflect the obligation not to expose individuals and their descendants to unacceptable risks. Doses below the limits are not automatically acceptable, because there is a requirement to reduce all doses to as low as is reasonably achievable, economic and social factors being taken into account. The dose limit recommended for members of the public is 5 *mSv* (one tenth of the limit for occupationally exposed persons). This limit applies to all sources of exposure, except natural background radiation and medical irradiation.

Figure 3·1 Dump sites used by the United Kingdom



Site	Total years
A* 1950-1963	14
B 1951, 1953	2
C 1969	1
D 1949, 1965-1966, 1968, 1970	5
E** 1971-1982	12
F 1963-1964	2
G 1962	1
H 1967	1
I 1957-1958, 1961	3
J 1955	1

* Hurd Deep

** Present site

3. PAST AND PRESENT PRACTICES

3.1 There have been two quite different types of UK sea dumping operations to dispose of low and intermediate level* radioactive waste. The site used for most of the early dumps was the Hurd Deep in the English Channel, where very low level contaminated sludges, initially from the effluent treatment plant at AERE Harwell and later also from the Atomic Weapons Research Establishment, Aldermaston and Atomic Energy Establishment (AEE) Winfrith were dispersed into the sea. The site had been used for many years for the disposal of dangerous material such as unstable ammunition. Although the material was disposed of in containers, the packages were designed to implode at depth, resulting in direct release and dispersion into the sea. This type of operation was therefore analogous to a pipeline discharge at the site. The first Hurd Deep disposal of radioactive waste was in 1950; subsequent disposals were carried out at least annually from 1951 to 1963. Dumping of radioactive waste ceased at the site in 1963 because the depth of the sea was less than the 2000 m minimum then suggested by the International Atomic Energy Agency (IAEA). Radioactive wastes deposited at the Hurd Deep totalled about 15,300 tonnes and contained 14.4 *TBq* of alpha activity and 41.2 TBq of beta and gamma activity. From 1964 onwards most low level sludges have been buried on land at the Drigg disposal site in Cumbria.

3.2 In the second type of disposal, contaminated solid wastes of low and intermediate activity were enclosed within a concrete shield inside a steel drum and dumped at a number of sites in the Northeast Atlantic (see Figure 3.1). The drums were designed to reach the floor of the deep ocean intact but in the knowledge that the radioactivity would over a period of years leak out and be dispersed into the sea, by which time the radioactivity would have been somewhat reduced by natural decay (see section 2.13). Such an operation was first carried out in the Northeast Atlantic by the UK in 1949 on an experimental basis. Subsequently deep ocean disposals were carried out about every two years up to 1961 when they became an annual event. In 1967, 1969 and from 1971 to 1976 these Atlantic disposals were coordinated by the European Nuclear Energy Agency, (later the Nuclear Energy Agency, NEA) of the Organisation for Economic Co-operation and Development (OECD). They were joint operations involving Belgium, France, Netherlands, Federal Republic of Germany, Italy, Sweden and Switzerland, although only the UK and the Netherlands took part in every dumping exercise. The UK also carried out separate operations in 1968 and 1970 but at a different location.

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* In describing wastes which have been dumped at sea, the terminologies 'low-level' and 'low and intermediate-level' have been used. We are satisfied that this has not reflected any difference of view about the policy or about the characteristics of the wastes. Under a new classification system set out in the Fifth Annual Report of the Radioactive Waste Management Advisory Committee, RWMAC, some of the wastes dumped at sea by the UK in the past would now be classified as 'intermediate level'. This does not represent a change in the activity of the waste dumped but only in its classification.

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The London Dumping Convention

3.3 The provisions of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (more usually known as the London Dumping Convention) currently controls the disposal of all waste by dumping into the sea. The Convention entered into force in 1975 the same year as it was ratified by the UK. Its secretariat is provided by the International Maritime Organisation (IMO), an agency of the United Nations. Under the provisions of the Convention, IAEA has defined high level radioactive waste the dumping of which is prohibited and has made recommendations about the factors to be taken into consideration by the competent national authority when it grants permits to dump other lower-level radioactive substances. The recommendations and definition are also presently subject to a separate review. Each national authority has to notify IMO of any dumping permits that have been issued.

The OECD Mechanism

3.4 In order to further the objectives of the Convention, OECD established in 1977 a Multilateral Consultation and Surveillance Mechanism for the sea dumping of radioactive waste. The Mechanism is administered by OECD/NEA. It provides for:

- ★ prior consultation with other countries participating in the Mechansim about proposed dumping operations
- ★ the establishment of guidelines, recommended practices and procedures for the safe dumping of radioactive waste
- ★ international observation of dumping operations by a representative appointed by the NEA Director-General
- ★ review at least once every five years of the suitability of any site used for disposal.

3.5 Since 1977 there have usually been two annual dumping operations in the Northeast Atlantic, one by the UK and one jointly by Belgium, the Netherlands and Switzerland.

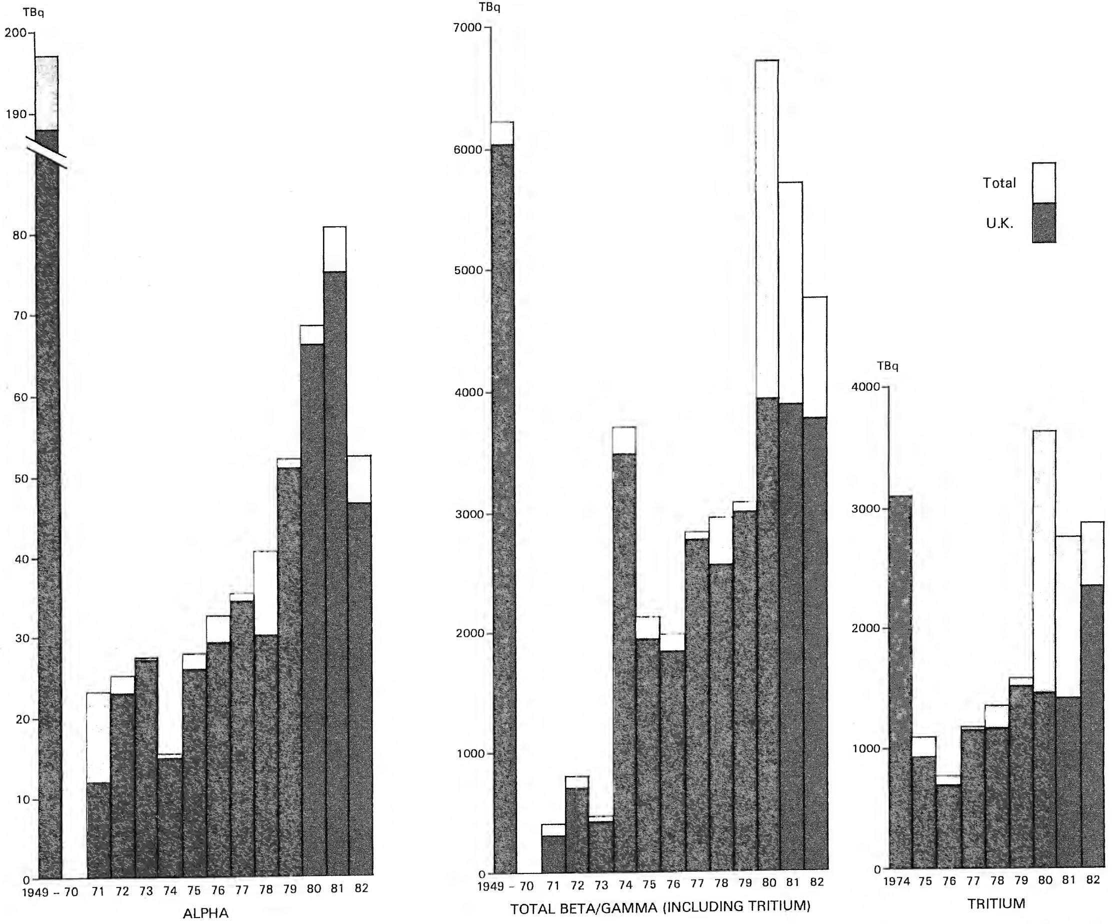
3.6 The locations of the Hurd Deep and the Atlantic disposal sites are shown in Figure 3.1. Although there was some redefinition of the shape of the present disposal site (site E in the Figure) in 1977, this site has in effect been used since 1971. It is located some 700 km from the nearest land (Spain) and 900 km south west of Land's End and is currently defined as being bounded by 16°00'–17°30'W and 45°50'–46°10'N; the average water depth is greater than 4000 m. Under the terms of the OECD Mechanism, the next site suitability review is due to be completed in 1985.

3.7 Figure 3.2 shows histograms of the total disposals of radioactive waste at the present site in the Northeast Atlantic since 1971. The total disposal in the Northeast Atlantic from 1949–1970 is also shown.

Sources and composition of the waste

3.8 As mentioned in section 3.1 the first sea dumping operations were mainly of sludge and some low activity scrap. The range of wastes included in recent operations is more diverse and includes radioactive chemical sludges and liquids, which have been solidified by incorporation into cement; solid wastes contaminated with radioactivity notably shredded

Figure 3·2 Quantities of radioactive waste dumped by year



plastics, metallic objects (pumps, tools, pipework, etc), laboratory trash, crushed glass, rubber gloves, protective clothing, air filters, spent *ion-exchange resins* and incinerator ash; 5–10% by weight of the material, mainly the plastics, is buoyant. Most of the waste is derived from operations at AERE Harwell, AEE Winfrith, BNFL Sellafield and Chapelcross establishments, Amersham International plc, the Central Electricity Generating Board (CEGB) nuclear power stations and from the Ministry of Defence (MOD). Wastes are also sent to AERE Harwell by various organisations, such as hospitals, universities and research laboratories, under arrangements known as the National Disposal Service. The contributions which each organisation makes in individual years varies according to operational requirements. Figure 3.3 shows the proportion attributable to the various waste producers over the last few years, so far as we have been able to ascertain.

3.9 The following broad distinction between the sources of alpha emitting, beta/gamma-emitting and tritium radionuclides can be made, although a range of radionuclides can be found in all sources.

★ **Alpha-active waste**
This is predominantly associated with nuclear fuel processes and the production and use of specific radionuclides for special applications. Nuclear fuel processes, particularly reprocessing and fuel studies, give rise to some uranium *isotopes* but mainly nuclides of plutonium and americium.

★ **Beta/gamma-active waste** (excluding tritium)
This arises mainly from four sources

  ★ *reprocessing* of nuclear fuel (for example plutonium-241 arises in this way)

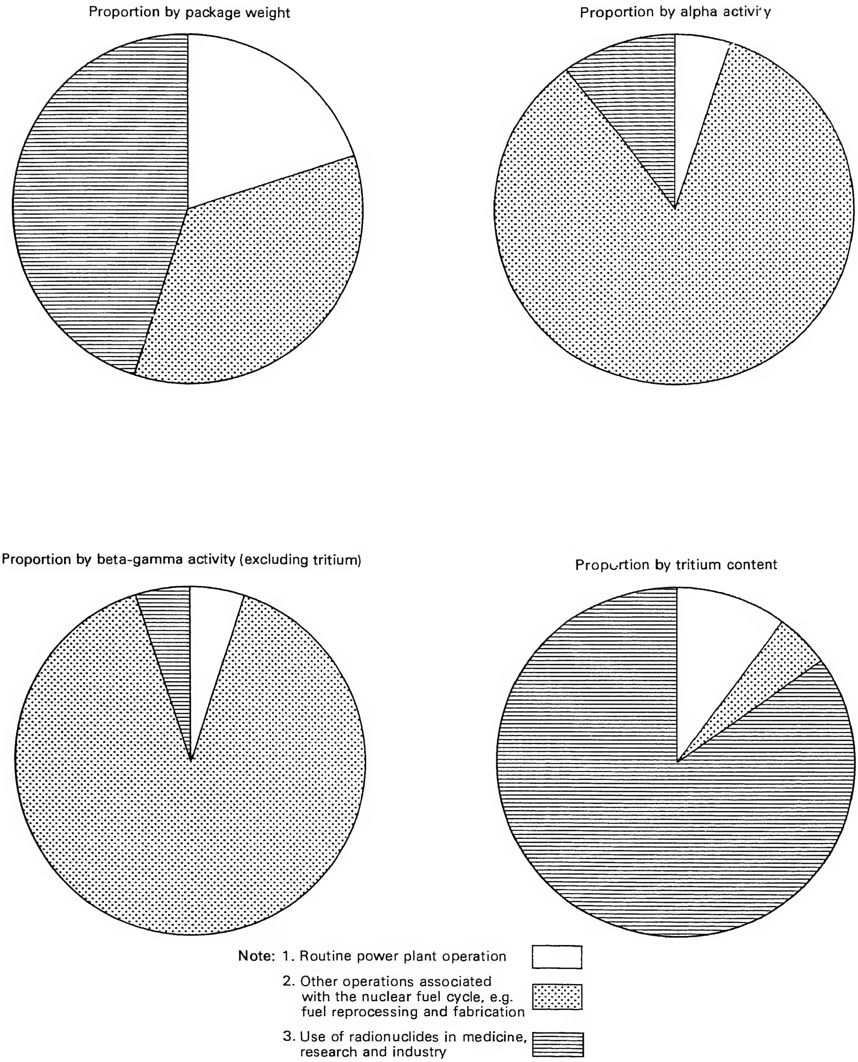
  ★ routine power plant operations (in particular strontium-90, caesium-137, iron-55, cobalt-58 and cobalt-60)

  ★ the production and use of specific nuclides in research, medicine and industry (for example carbon-14 and iodine-125)

  ★ the decontamination and decommissioning of redundant plants and equipment producing waste containing a range of nuclides principally as surface contaminants on building rubble and pipework and as induced activity in metals.

★ **Tritium waste**
Tritium waste is very much less radiotoxic than other beta-active wastes. This is because tritium is a very *soft* beta-emitter with not enough energy to penetrate the skin. If contaminated food or drink is ingested then a dose can be received, but because the emission is so soft the amount of tissue damage is very small. For example ICRP has estimated the annual limit of intake for workers to be 4×10^6 Bq for caesium-137 whereas for tritium the limit is 3×10^9 Bq; that is, the effect of tritium is a thousand times less than that for caesium-137. For this reason the amount of tritium waste has been quoted separately over recent years. It essentially arises from medical research and industrial applications.

Figure 3·3 Origins of waste dumped by the UK



Proportion by package weight

Proportion by alpha activity

Proportion by beta-gamma activity (excluding tritium)

Proportion by tritium content

Note: 1. Routine power plant operation □

2. Other operations associated with the nuclear fuel cycle, e.g. fuel reprocessing and fabrication ▒

3. Use of radionuclides in medicine, research and industry ▤

The Committee was unable to obtain a more detailed breakdown of the origins of UK waste, but it is understood that the above apportionments relate to recent years and cover all the wastes, including those from the Ministry of Defence

3.10 Information about the radionuclide composition of the waste from the European countries which have dumped at sea shows that the composition of the total waste varies considerably from year to year. The proportions of alpha and beta-gamma radionuclides from all countries dumping in the Northeast Atlantic between 1949 and 1982 are shown schematically in Figure 3.4. Plutonium isotopes and americium-241 account for over 96% of the alpha activity dumped, whereas tritium and plutonium-241 account for over 87% of the beta-gamma activity dumped. The remainder of the long-lived beta-gamma activity comprises essentially strontium-90, caesium-137 and cobalt-60. The total quantity of UK waste dumped in the Northeast Atlantic between 1949 and 1982 was 73,530 tonnes in 149,627 packages.

Structure of responsibility

3.11 The UK Government is responsible for devising a national strategy and defining policies for radioactive waste management. It is also responsible for necessary administrative and statutory controls over the storage and disposal of radioactive waste. Executive and financial responsibility for the management of UK radioactive wastes lies however with the nuclear industry through whose operations the wastes mainly arise.

3.12 The main organisations with regulatory and safety functions and those advising government are:

- ★ MAFF, which authorises, monitors and undertakes research on radioactive releases to the environment*
- ★ DOE which through its Radiochemical Inspectorate regulates all disposals in England, in some cases jointly with MAFF.* DOE is also developing an overall UK waste management strategy and is funding research
- ★ HM Nuclear Installations Inspectorate of the Health and Safety Executive which is responsible for occupational safety on nuclear sites
- ★ NRPB, which advises on the acceptability and applicability of internationally recommended standards (including ICRP's) in the UK. It carries out research, and assesses the radiological impacts of all practices, including waste disposal
- ★ The Radioactive Waste Management Advisory Committee (RWMAC) which provides independent advice to Government on waste management issues.

Authorisation

3.13 The disposal of radioactive waste in the UK is subject to the provisions of the Radioactive Substances Act 1960. In England, prior authorisation for disposal to sea must be given by the Secretary of State for the Environment and in the case of major nuclear establishments this is undertaken jointly with the Minister of Agriculture, Fisheries and Food. In Scotland and Wales, responsibility lies with the respective Secretaries of State. For disposal at sea in UK territorial waters, from a British registered

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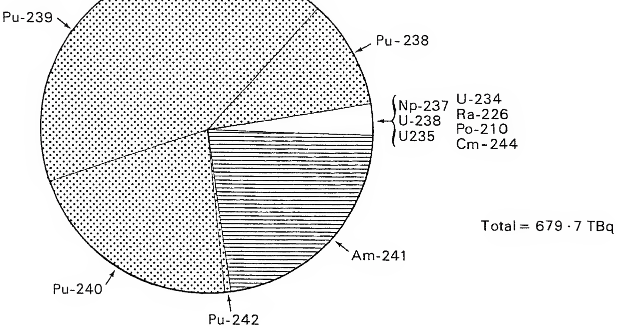
* Slightly different regulatory arrangements apply in Scotland, Wales and Northern Ireland.

Figure 3·4 Radionuclides dumped 1949 - 1982

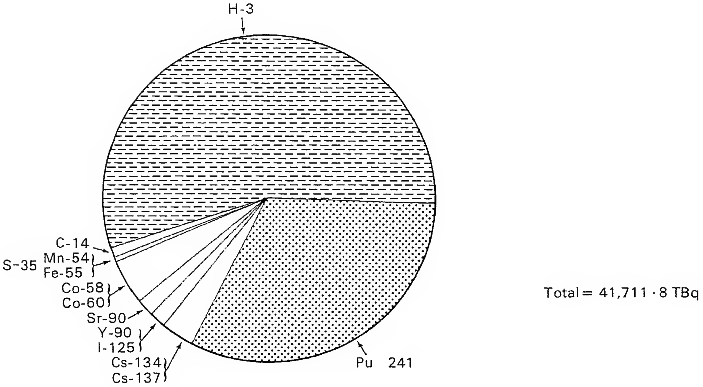
(a) Alpha

Pu - Plutonium
Np - Neptunium
U - Uranium
Ra - Radium
Po - Polonium
Cm - Curium
Am - Americium

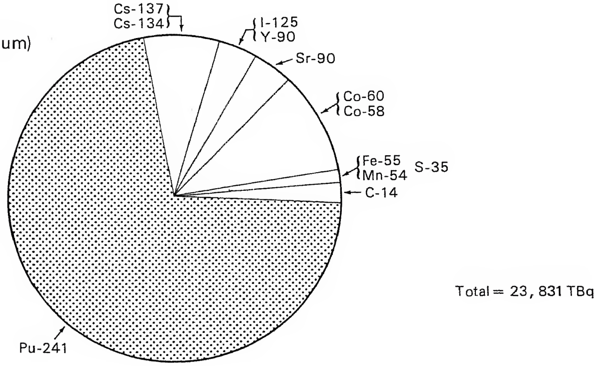


(b) Beta-gamma

H-3 - Tritium
C - Carbon
S - Sulphur
Mn - Manganese
Fe - Iron
Co - Cobalt
Sr - Strontium
Y - Yttrium
I - Iodine
Cs - Caesium
Pu - Plutonium



(c) Beta-gamma (excluding tritium)



vessel or from a vessel loaded in a British port, a licence must be granted by the appropriate licensing authority under the Dumping at Sea Act 1974. Since all UK sea disposal operations have started from English ports the licences have been issued by MAFF. A certificate of approval for transport of the waste (under orders made by virtue of the Radioactive Substances Act 1948) is also required from the Department of Transport.

Practical arrangements

3.14 From the first UK operation in 1949 until the establishment of NIREX in the summer of 1982, all the practical arrangements for UK sea disposal operations have been made by UKAEA through AERE Harwell. This has normally involved establishing the quantities of waste which producers wish to dispose of, obtaining the relevant authorisations and licences, chartering a suitable vessel, organising transport to port, supervising the loading of the waste onto the vessel and subsequent dumping, providing an escorting officer and general liaison with the Authorising Departments. Costs incurred by UKAEA (and latterly NIREX) are recovered in full from the waste producers contributing material for disposal.

3.15 In recent years the port of Sharpness has been used. The waste normally travels from the packaging establishment by road to the nearest railhead or is loaded direct onto the train if there is a private siding. It then goes on by rail to Sharpness Docks. The times of the trains are programmed so that all waste delivered can be loaded onto the vessel the same day. Strict precautions are taken to ensure that the waste poses no danger to the public. To confirm that no one has been exposed to significant radiation all workers handling the waste are provided with *film badges* which record any radiation to which they have been exposed. At the end of every work period workers are checked with radiation detectors to ensure they have not been contaminated with radioactive material. The rail wagons and the ship, after unloading, are also checked by health physicists to ensure there has been no spillage of radioactive material. Experience in recent years has confirmed that the maximum individual exposures have been only a very small fraction of the levels recommended by ICRP (see section 2.25).

Packaging

3.16 The packages currently used for deep sea disposal have to meet a number of requirements. They have to provide shielding and containment of the waste during handling and transport and a means of delivering the waste to the seabed (approximately 4000 m depth) without the loss of the waste on the way down.

3.17 Prior to 1966 the responsibility for the design of packages rested solely with individual countries. However since that date certain conditions have been specified with packaging guidelines published by NEA in 1974, and revised following the establishment of the OECD Mechanism, in 1979. Further guidance was published by IAEA in 1981.

3.18 Waste packages consist of a container and waste in an integrated design. Packages are produced to two basic designs, either monolithic or containing air spaces (voids); the latter is more common. All containers must have a specific gravity of not less than 1.2 to ensure that they sink.

3.19 In **monolithic packages** (see Figure 3.5), the waste is incorporated in a matrix which may be cement, bitumen or polymer. The encapsulated waste is then enclosed within a sealed container and surrounded by a concrete lining for shielding.

3.20 Waste in monolithic packages includes sludges, resins, evaporator concentrates, and discrete contaminated or irradiated items set in the encapsulating medium. Discrete solid items may also be incorporated into the encapsulating medium directly inside the outer container. Liquid waste, particularly tritium, is solidified by incorporating into concrete or an absorbent material, the latter necessitating use of a second sealed enclosure containing further absorbent.

3.21 **Void-containing packages** (see Figure 3.6) comprise a concrete lining around the inner waste container(s) for strength and shielding. The thickness of the concrete shell depends on the radiation level of the waste. To ensure that no significant pressure differential builds up between the inner part of the package and the surrounding sea water as the package descends, an inward water pathway or vent is incorporated into the design, thereby preventing collapse and destruction of the package as an integral whole. Pressure equalization devices include the use of simple tubes and non-return valves.

3.22 Waste in void-containing packages may include discrete items, shredded laboratory waste with surface contamination or small irradiated components with induced activity.

3.23 Pressure build-up tests on models have been made by UKAEA and limited sea trials have been successfully carried out on full-size containers. Guidelines on packaging requirements have been developed over many years. UK waste packages must currently comply with a MAFF Code of Practice as well as Guidelines for packages agreed by OECD/NEA.

3.24 In order to reassure the Authorising Departments that packages are being fabricated in accordance with the Code of Practice and Guidelines, MAFF Inspectors make regular visits to packaging establishments. MAFF have indicated that on occasions they have asked for packages to be rejected because they appear not to comply with the requirements. Such waste then has to be repackaged.

3.25 There is no firm information to predict when the packages will disintegrate once dumped in the sea. It is judged that the outer mild steel drum will have a life of 30–40 years and the reinforced concrete lining will last for about 300 years or even longer.

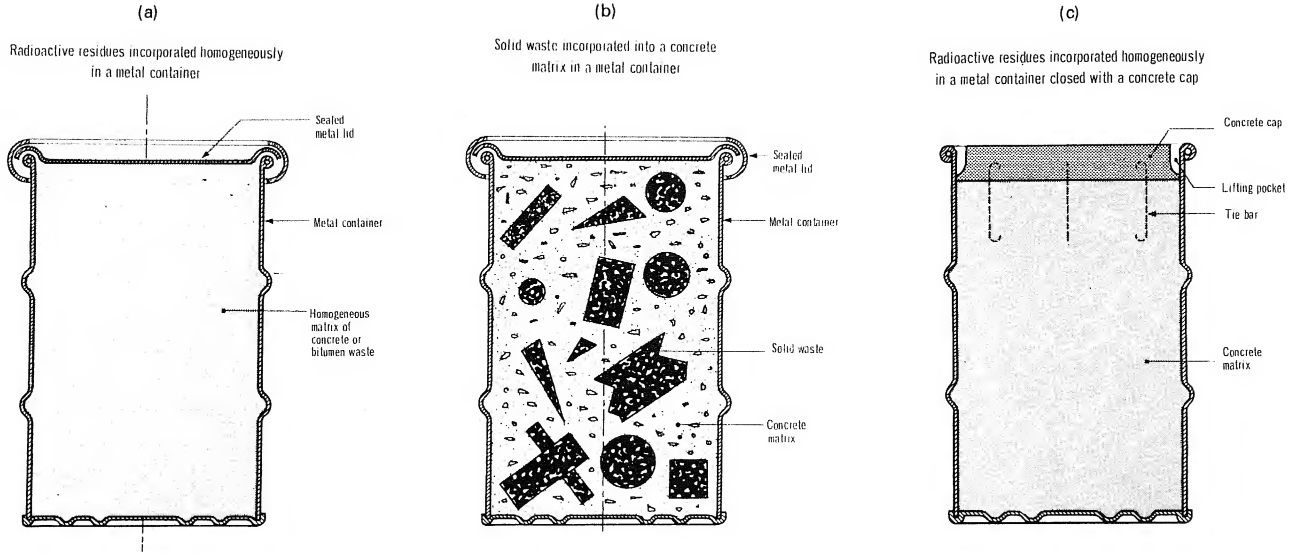
3.26 The packages may thus remain intact on the seabed for a long period of time. They are widely scattered over a large area, and it would be practically impossible and extremely expensive to recover even a significant proportion of them should that be considered necessary in the future. Once their contents have been released, recovery of the radioactivity would not be possible by any means of which we are aware.

Present practices by other countries

3.27 At present the only countries committed to sea dumping are the UK and Belgium.

Figure 3.5 Types of monolithic packages

(acceptable under NEA guidelines for sea dumping packages)



(a) Radioactive residues incorporated homogeneously in a metal container

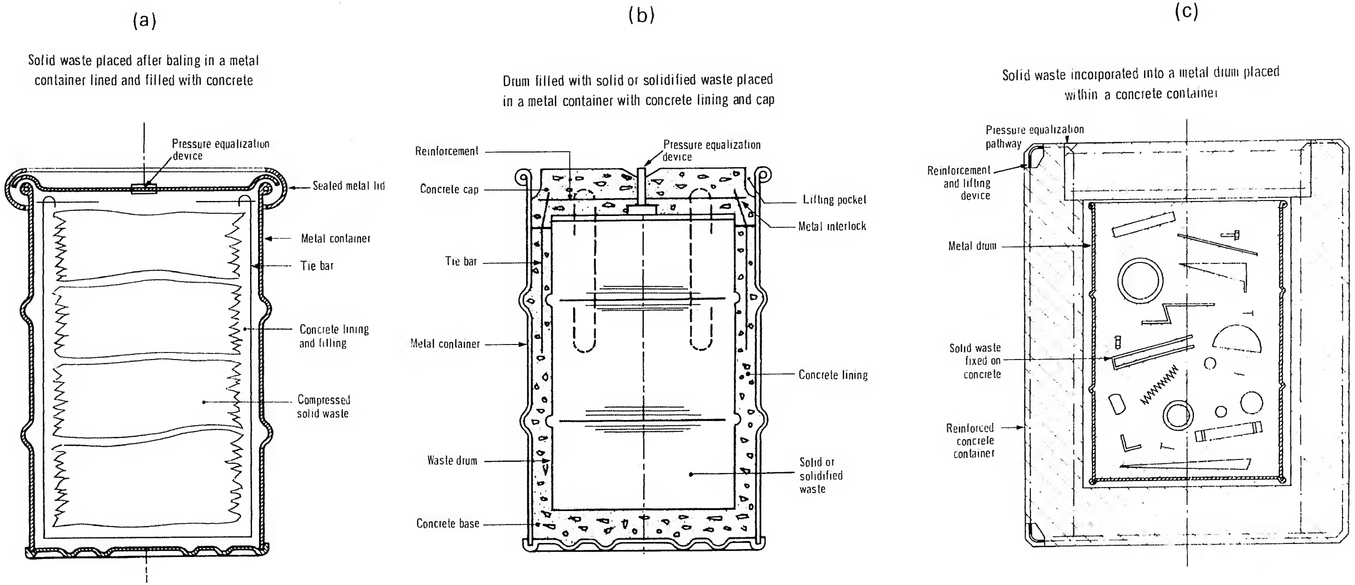
(b) Solid waste incorporated into a concrete matrix in a metal container

(c) Radioactive residues incorporated homogeneously in a metal container closed with a concrete cap

Notes: see Figure 3.6

Figure 3.6 Types of void-containing packages

(acceptable under NEA guidelines for sea dumping packages)



(a) Solid waste placed after baling in a metal container lined and filled with concrete

(b) Drum filled with solid or solidified waste placed in a metal container with concrete lining and cap

(c) Solid waste incorporated into a metal drum placed within a concrete container

Pressure equalization device
Sealed metal lid
Metal container
Tie bar
Concrete lining and filling
Compressed solid waste
Reinforcement
Concrete cap
Tie bar
Metal container
Waste drum
Concrete base
Pressure equalization device
Lifting pocket
Metal interlock
Concrete lining
Solid or solidified waste
Pressure equalization pathway
Reinforcement and lifting device
Metal drum
Solid waste fixed on concrete
Reinforced concrete container

Notes: 1) Although the UK does use monolithic packages, vented packages (type (b) above) are more common

2) Type (c) above is not used by the UK and is shown for illustrative purposes (see figure 5.2)

Source: OECD/NEA guidelines for sea dumping packages of radioactive waste 1979

★ The Federal Republic of Germany is not presently using the sea disposal option for radioactive waste and is proceeding with land disposal.

★ France is presently disposing of waste on land, and whilst it is developing new land facilities it has not ruled out the possibility of sea disposal for certain categories of waste, notably tritium.

★ Japanese proposals to dump waste in the Pacific have aroused considerable opposition, resulting in the Japanese government reconsidering their policy. Our information is that there are at present no proposals to dump.

★ The Netherlands stopped sea dumping in 1983 because of lack of public acceptability.

★ Switzerland has not made a decision on further sea dumping proposals and is awaiting the outcome of the present international reviews.

4. THE OCEANOGRAPHY OF THE DUMP SITE

4.1 Information about the physics, chemistry, biology and geology of the site and the world's oceans comes from studies by universities and government research laboratories, notably those of MAFF and NERC in the UK, as well as from studies by similar bodies in many other countries. MAFF normally funds two deep sea research cruises a year, one of which usually includes sampling at the dump site.

Location

4.2 The site is located in the foothills of the Mid-Atlantic Ridge, southwest of the Porcupine Abyssal Plain (see Figure 4.1). It is a rectangle 37 x 115 km, roughly the dimensions of Cornwall, elongated east to west and extending from 16°00' to 17°30'W and from 45°50' to 46°10'N. The average depth is 4400 m (about 2.5 miles). The Mid-Atlantic ridge effectively divides the deep North Atlantic into two basins, and the continental slope of the European continent some 500 km or more from the site forms the eastern edge of the deep basin in which the site lies.

Topography

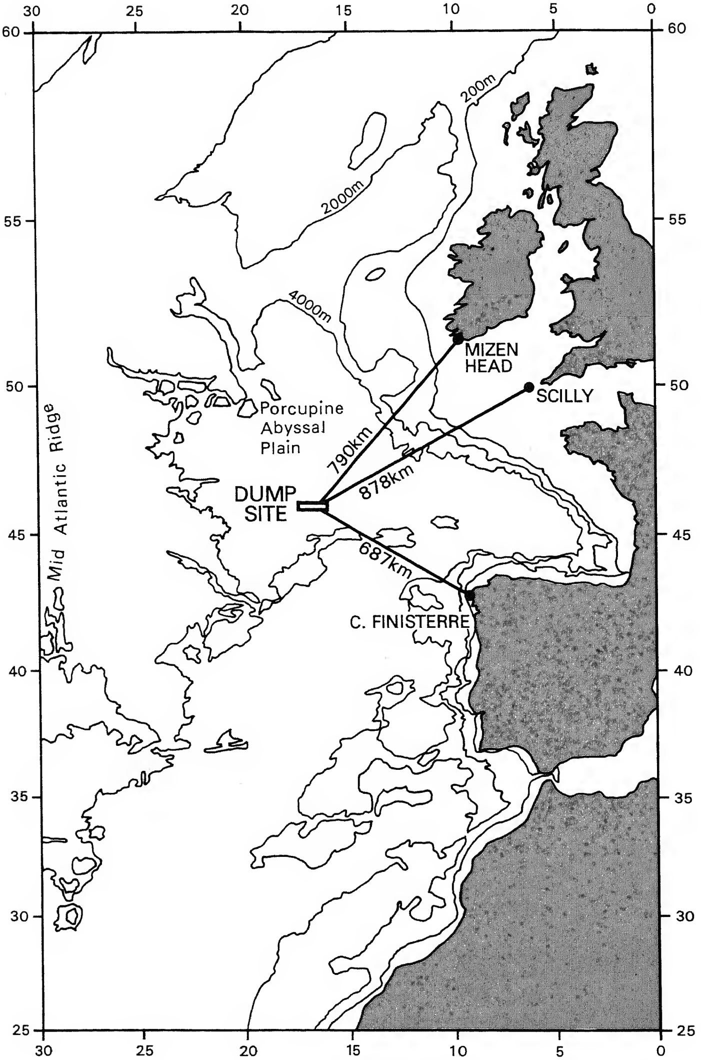
4.3 The principal feature of the western part of the site is a flat-floored valley running southwest to northeast opening at its northern end onto the Porcupine Abyssal Plain. Its maximum depth is over 4750 m. The eastern part of the dumpsite has an irregular topography with hills rising to 3850 m below the sea surface and valleys descending to 4700 m.

4.4 The underlying solid rocks are mostly covered by sediments about 350 m thick; these sediments are composed primarily of the skeletal remains of tiny marine organisms, and have gradually accumulated at a rate of about 20 mm per thousand years (20 m per million years). Core samples show the sediments of the region to be stable except for occasional slumps of sediments from the sides of steeper hills.

Biology

4.5 The biological samples taken from the site suggest that its *fauna* is typical of the general area. Populations of marine organisms vary considerably from the sea surface to the deep sea floor both in species and in abundance. The total weight of living material (the biomass) in the water column falls off rapidly below the surface layers and that present at 4000 m is only about one hundredth of that near the surface. There is however a slight increase as the sea bed is approached. The total mass of organisms living near or in the sea bed is very small, probably less than 3 grams per square metre in the bottom 1000 m of sea water and sediment. Few fish inhabit the waters at the site, the *genus* Coryphaenoides (the rat tails) being most common. The amphipod Eurythenes gryllus, a voracious scavenger, is also found in some numbers. The upper 5–10 cm of the sediment is of relatively uniform consistency, stirred by the burrowing of organisms, notably nematode worms which occur in large numbers. This stirring by animals is known as bioturbation. Recent photographs by French scientists and studies by MAFF provide no evidence that the drums containing the wastes are a focus for colonisation by presenting a solid base onto which organisms might attach.

Figure 4·1 Location of the present Northeast Atlantic dump site



4.6 Although some marine organisms that live in surface waters may migrate down to 2000 m during the day, in general the deep and shallow water populations are quite separate and there is no movement between. The eggs of a few deep living species are buoyant, and it is possible that their young may develop at shallow depths before returning to deep waters.

4.7 The majority of fish caught for human consumption world wide is obtained from the top 200 m of the ocean. Most species are taken from the continental shelf and have not spent any part of their life cycle in deep waters. Annual catch statistics show that very few species are caught near the site. Two possible exceptions are some cephalopods (squid), which are being taken in increasingly large numbers, and some tuna and tuna-like fishes which may spend part of their annual migrations over the dump site area. The espada, or black scabbard (Aphanopus carbo), is taken by long line from depths down to 1500 m near Madeira.

Currents and water circulation

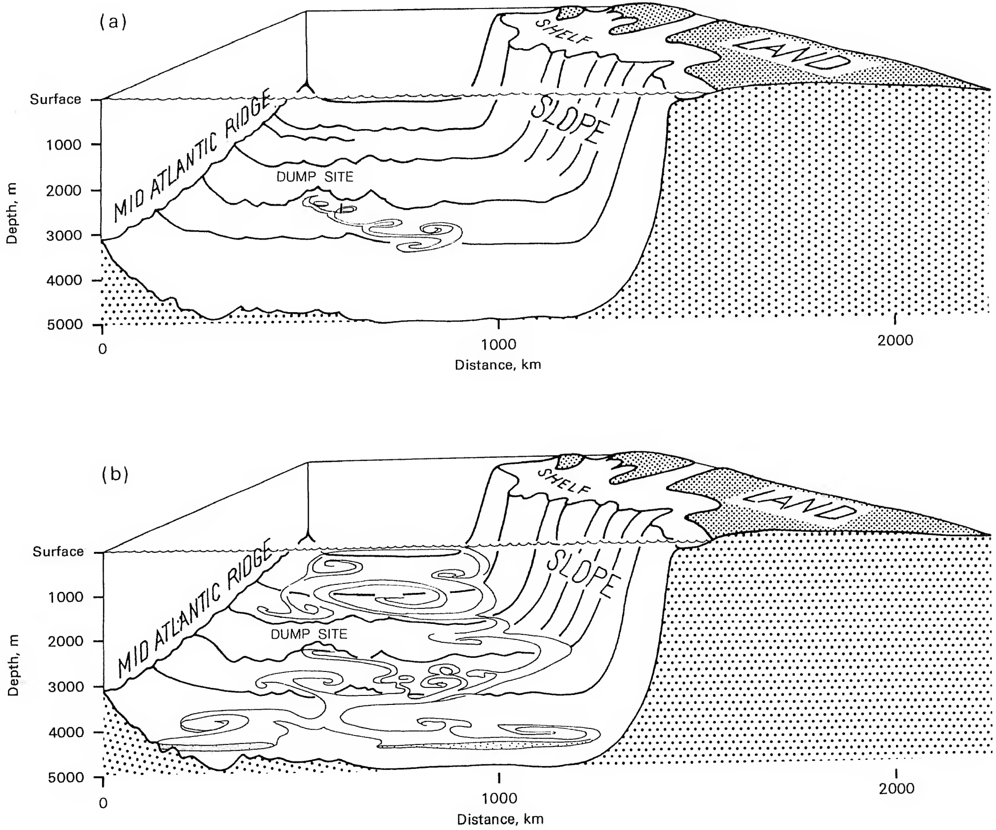
4.8 The water movement around the site is variable in direction and weak. The largest currents rarely exceed 20 cm per second. The tides, and motions associated with the Earth's rotation which have a *wave period* of about 16.5 hours are important in the short-term. In the long-term, eddies (less vigorous cousins of the cyclones and anticyclones in the atmosphere) take 20 days or more to pass by. The fluctuations are seasonal, with strongest currents in late winter. The net movement of the deep water (that is the deep flow) in the area of the dump site is only 1 or 2 cm per second near the sea bed and whilst the direction of this flow is not totally certain, it is most likely to be northwards, consistent with a large-scale anticlockwise water movement in the deep Atlantic Ocean to the east of the Mid-Atlantic Ridge. The largest currents near the sea bed at the site appear to be sufficient to resuspend some of the sediment from the sea bed, contributing to a near-bottom layer of fine particles (a 'nepheloid layer').

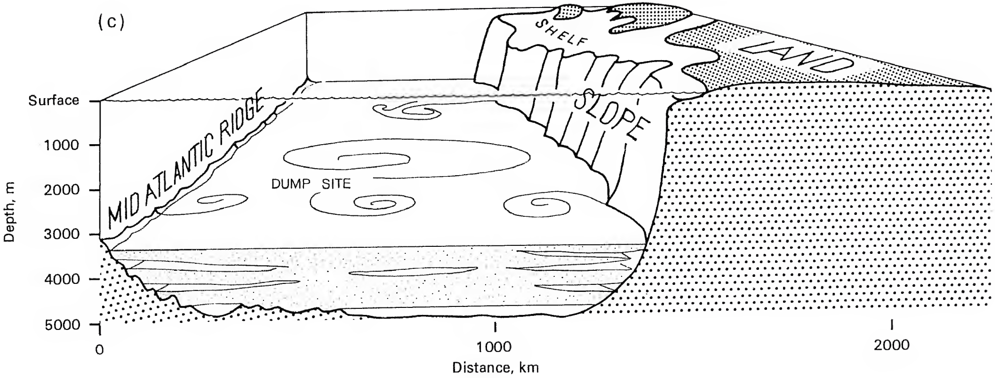
4.9 Water in the ocean is not uniformly mixed but is stratified, becoming colder and denser as depth increases. This density stratification inhibits vertical motions and mixing, and these factors together with the restriction imposed by the Earth's rotation and the local topography provide constraints on the way in which the water, dissolved substances and suspended particules can move.

Dilution, and adsorption onto sediments

4.10 Radionuclides escaping from the canisters on particles or dissolved in the sea water will initially be confined to a layer adjacent to the sea bed called the 'benthic boundary layer', some few tens of metres thick in which dilution will first occur. Further dilution will occur by diffusion as the material is carried from the site in a variable and meandering plume (see Figure 4.2a). The path of this plume will be determined by the fluctuating currents, but will keep approximately to the same density surface since vertical mixing is severely restricted by the density stratification of the water (see Figure 4.3). The concentration of material in the plume will be 'streaky' because of the changing speed and direction of water movement and of its density as the material is released from the containers, because of the variable supply from the scattered drums, and because of the contortions and stretching imposed by the stirring eddies. The amount of radionuclides remaining in the water will be reduced both because of their natural decay but also by their removal to the sea bed by *adsorption* onto

Figure 4.2 Release of a plume of radionuclide from the site





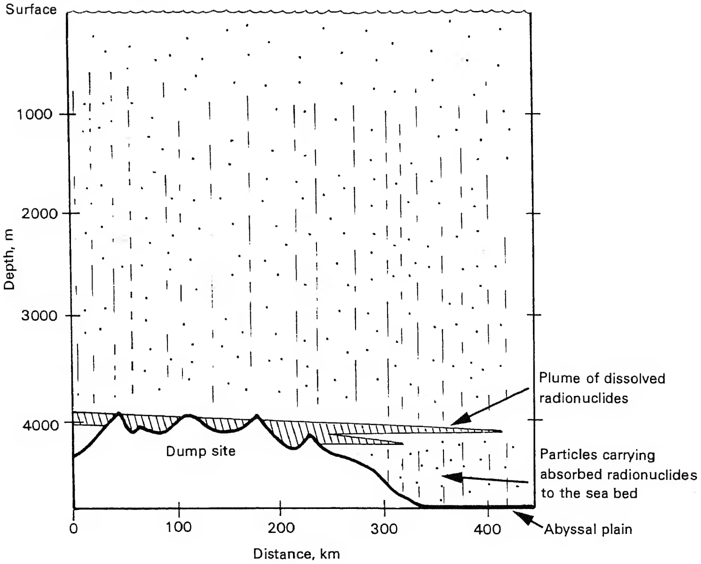
These are sketch views looking north. The scales are very approximate and the vertical scale is greatly exaggerated.

(a) shows the convoluted plume as it might appear days to months after release of material from the drums.

(b) shows its gradual circulation around the basin over a time scale of 10-20 years. The concentration is being considerably reduced by dilution, sediment scavenging, and for short lived radionuclides, by their decay.

(c) shows material filling the basin after 50-100 years and gradually being diffused upwards. The water carrying dissolved radionuclides from the site is underlain by denser water from the south. A meandering plume of greatest concentration will continue near the site until the material from the drums is exhausted.

Figure 4.3 Spreading of material from the site


Surface
1000
2000
3000
4000
Depth, m
Plume of dissolved radionuclides
Dump site
Particles carrying absorbed radionuclides to the sea bed
Abyssal plain
0
100
200
300
400
Distance, km

This is a diagramatic vertical section showing the plume of dissolved material spreading from the seabed at the dump site along the density surfaces, and the scavenging of radionuclides by sedimenting particles.
The scales are approximate and the vertical scale is greatly exaggerated.

sedimenting particles. The physics and chemistry of this adsorption is a complex process. It is known to depend on the nature and chemistry of the sedimenting particles and the surrounding sea water, as well as the chemical speciation of the radionuclide being adsorbed, and may lead to much higher concentrations of radionuclides on the particles than in the water.

4.11 Water carrying dissolved radionuclides will eventually reach the foot of the continental slope, but closer approach to shore will be impeded by the density stratification, and rather than flowing up the slope, the water will be confined to run roughly parallel to the depth contours. It is estimated to take on average some 20 years for the dissolved material to circulate around the deep water of the ocean basin in which the site lies (see Figures 4.2b and 4.2c), and about 200 years from the time of release before it extended upwards to reach a depth of 2000 m, the maximum depth to which surface living organisms are known to migrate.

4.12 Over longer periods of time, those radionuclides which have not already decayed or been removed onto sediments may be transported, diluted and mixed throughout the ocean, although at very low concentrations. Vertical transfers between the surface and deep waters occur most readily in arctic regions where the density stratification is reduced and where the density surfaces from the surface water trend downwards towards the deep water of the dump site. Rapid upwelling, the process by which cold water is brought from depth to the surface in some parts of the ocean, is confined to the upper 1000 m or so of certain coastal regions and does not provide a direct path from the deeper water to the surface.

4.13 The highest concentrations will always be encountered in the neighbourhood of the site. Fluctuations in concentration will continue to occur but these will be diminished when averaged over larger and larger volumes or over longer periods of time.

4.14 Thus some radionuclides will be transported away in solution to be diluted and diffused in the ocean water, some will be taken up and spread to a certain extent by marine organisms, whilst others may be adsorbed onto particulates falling through the water column and into the upper sediment layers. The eventual region of influence of any particular dumped nuclide will depend on its potential to adsorb on particles and on its half life. These factors are all included in models used to describe the spread, and to assess the hazards, of dumped materials (see chapter 5).

5. ESTIMATION OF DOSES

Why modelling?

5.1 At first sight the problem of measuring the effects of dumping radioactive waste seems straightforward. It appears to be a matter of taking samples of the water from the vicinity of the dumpsite, together with samples of the bottom sediments and samples of the *biota*, and analysing the material for radioactivity.

5.2 Unfortunately that is not the case. The material is contained in steel drums which are sunk at great depths. The drums delay the release of radioactive materials, some substances leaking out of the drums more quickly than others. The present level of activity in the water arising from the dumped material is so very small that it is unlikely to be detectable from the background radiation (see section 2.14) given off by the naturally occurring radioactive materials in the water and the radioactivity already present arising from the testing of nuclear weapons.

5.3 The release, dispersal and fate of the radioactive materials dumped at the present Northeast Atlantic dumpsite cannot therefore be measured, so it has been calculated and modelled. MAFF and NRPB have established siderable expertise in this *modelling*.

Modelling techniques

5.4 The objective of the modelling is to predict the future quantities or concentrations of radioactivity in each part of the ocean and thence to estimate the doses, and hence hazard, to both man and marine life. The modelling divides into three parts (see Figure 5.1).

- ★ a waste package model – a description of the release of the waste from the containers into the marine environment.
- ★ models of dispersion – a set of models which describe the dispersion of radioactivity in the ocean water and sediments or through a food chain.
- ★ dose assessment – the assessment of doses to man through ‘exposure pathways’, for example consumption of contaminated fish or contact with material on a beach.

The waste package model

5.5 The various types of waste packages have been described in Chapter 3. In some of the early calculations it was simply assumed that waste was released directly into the water as soon as the package arrived at the sea bed. Release was thus instantaneous at a rate which corresponded to the rate at which dumping took place. MAFF and NRPB are now however using a more realistic model in which the rate of release to the environment depends on package type. Some packages remain intact for a period of years during which time radioactive decay reduces the activity of the contents. Release occurs gradually over subsequent years as the concrete matrix of the package is assumed to disintegrate, before a final total release of the remaining contents as the concrete collapses. Other packages, those with vents (see section 3.21) begin to release their contents immediately on

Figure 5.1 Modelling framework used in radiological assessment

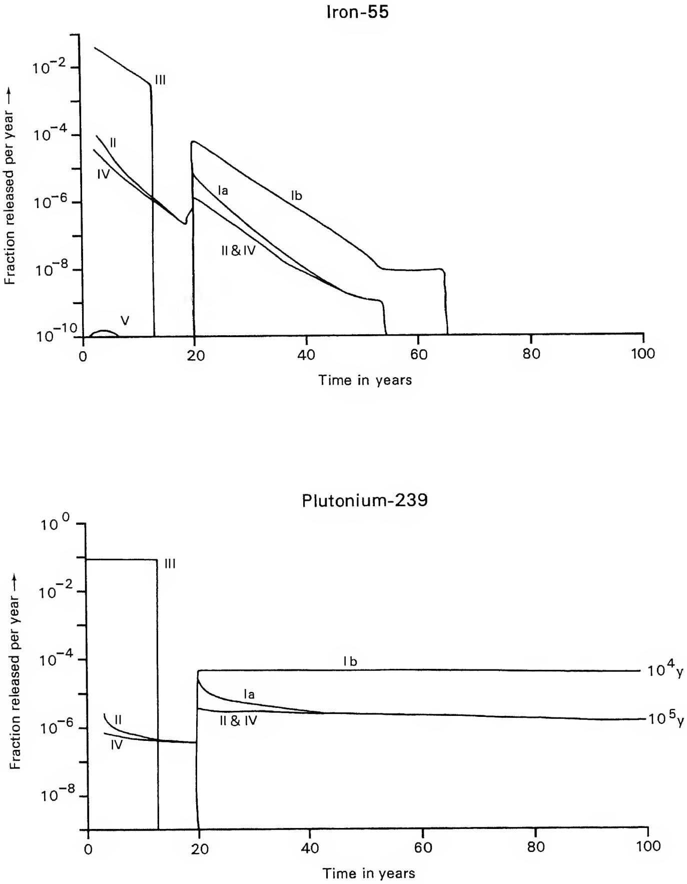
Parts of system included in model	Model	Major processes included in model
Canister and lining Waste form	Waste package ↓ rates of release of radionuclides into the ocean, as a function of time ↓	Canister corrosion Degradation of package linings and caps Release of radionuclides from waste forms
Bottom sediments Benthic boundary layer (water and particulates) Open ocean (water and suspended particulates) Coastal waters	Ocean dispersion and sedimentation ↓ radionuclide concentrations in water and sediments, as a function of time ↓	Diffusion and advection Interactions between radionuclides and suspended particulates and bottom sediments
Exposure pathways – sea foods, beaches, atmosphere, salt, water Marine organisms	Dose to man and organisms	Reconcentration of radionuclides in marine organisms, beach sediments, aerosols Radionuclide intake and metabolism by man and organisms

arrival at the sea bed. Figure 5.2 shows estimates of the fractions of waste released per year from packages of six different types and for two radioisotopes, plutonium-239, which has a half-life of 24,113 years, and iron-55, with a half-life of 2.7 years. Because of its short half-life the latter decays significantly during the period before the total collapse of the waste package.

5.6 The inventory of wastes dumped up to 1983 and information about the disintegration of the different types of package, have been used to estimate present and future rates of release, supposing that no further dumping takes place. Figure 5.3 is a comparison of the total amount of radioactivity which has been dumped per year with that released from the packages into the sea water per year, for the two radionuclides, iron-55 and plutonium-239. The effect of containment significantly reduces the amount of the short half-life radionuclide activity entering the sea water but is obviously less effective in reducing that of the long-lived plutonium isotope.

5.7 Estimates are also available for future dumping, based on an assumption of its being continued from 1984 to 1989 at ten-times the average inventory for the years 1978 to 1982 and making a pessimistic assumption that waste is released as soon as the containers reach the sea bed.

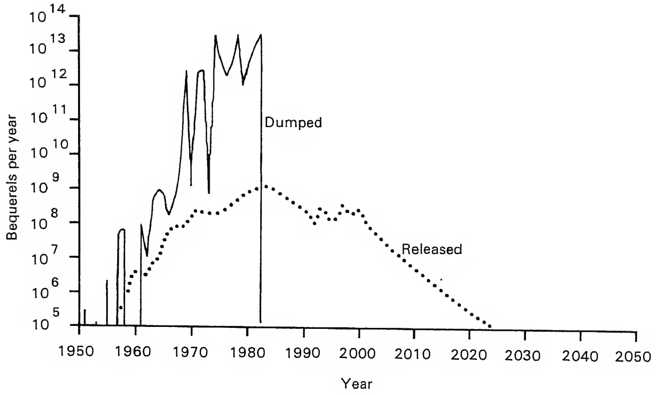
Figure 5·2 Fractional release rates from the package types as calculated by the model



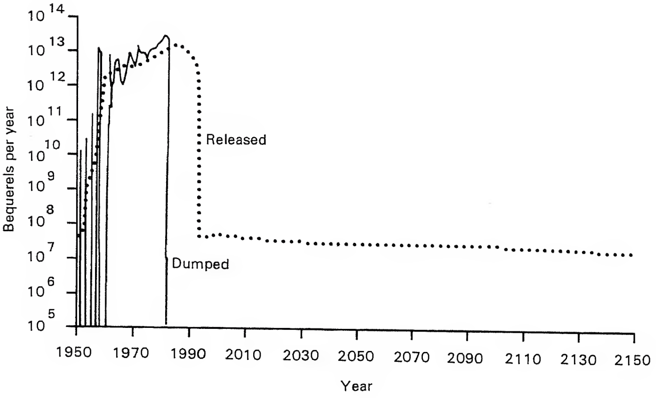
Ia	Monolithic, in concrete, steel lid [see Figure 3.5 (a) and (b)]
Ib	Monolithic, in bitumen, steel lid [see Figure 3.5 (a)]
II	Monolithic or multistage, in concrete, concrete cap [see Figure 3.5 (c)]
III	Vented, loose packed [see Figure 3.6 (a)]
IV	Vented, encapsulated in concrete [see Figure 3.6 (b)]
V	Solidified in concrete, concrete container [see Figure 3.6 (c)]

Figure 5·3 Comparison of dumping rates and release rates for two radionuclides as calculated by the model

Iron-55 Dumped and released



Plutonium-239 Dumped and released



Models of dispersion in the ocean

5.8 The philosophy of modelling has recently been reviewed by a GESAMP* panel. That panel also made proposals for future models, some of which have already been adopted by MAFF and NRPB. The models can only match in their sophistication the level of knowledge of the processes which occur naturally in the ocean and, of these processes, the models should include only those which are essential in determining the concentrations of radionuclides over volumes of the ocean or for periods of time in which they may be important. It is impossible and unnecessary to predict future concentrations of radionuclides at all times and in every drop or particle of sediment in the ocean, since it is an integrated effect which determines a dose to humans and biota. The fluctuations tend to be less important than the mean value when averaged over periods of time and volumes over which the fluctuations persist, and which span the lifetime and movement of marine animals. When considering only very long-term effects over large areas of the ocean, it is shown in the GESAMP report that biological mechanisms of transport are much less effective than physical ones, and the dispersion models are therefore based mainly on physical processes. Nevertheless, the biological mechanisms, and especially those in shallow waters from which food is obtained, must be accounted for in assessing the transfer and dose to man. (Biological processes are also accounted for in the 'pathway' models of which an example is given in section 5.16.)

5.9 It is unnecessary for any model to incorporate specifically all the processes or all the motions which occur in the ocean, from those which move a grain of sand to those which force the circulation of water around a 2000 km wide ocean basin. It follows that the models should contain a considerable degree of simplification. Some processes have to be 'represented' and cannot be included in their full detail. Of these the most important is that of diffusion. Rather than describing specifically all the minute structure of the turbulent eddies which lead to mixing, these are included in a collective way in some form which represents their net effect.

5.10 The distributions of naturally-occurring substances result from the integrated effects of the many processes and fluctuations in the ocean, such as currents, eddies, turbulence and waves. One means of checking the models is to use them to simulate these distributions and to compare predictions with observations. For example, the concentration of thorium-230, which has a half-life of 75,200 years and which results from the decay of naturally occurring uranium dissolved in sea water, increases from the surface to the sea bed largely as a result of 'scavenging' by sinking particles. The model developed by MAFF and NRPB (see sections 5.14 and 5.15) has been adjusted to correctly simulate this distribution.

5.11 There are models providing a basis for rough assessment which can be expressed as mathematical equations, with solutions which can be found directly using conventional mathematics or analytical methods. The 'solutions' might, for example, relate the concentration of a radionuclide in the water or on the sediment at some distance from the dump site to the rate at which it is released. These are however very idealised representations of the ocean. The solutions do not apply in a geometry with a shape and depth which matches that of the real ocean basins, nor can the models include all the processes which may be important. Their value is that they can identify the distances and times over which concentrations vary, they may be useful in establishing the largest concentrations which could occur, and they may be helpful guides in finding the most important processes by comparing the results of including only one or other in the calculations.

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* GESAMP:– Joint Group of Experts on the Scientific Aspects of Marine Pollution, set up by a consortium of UN agencies concerned with the oceans. Report No 19, An oceanographic model for the dispersion of wastes disposed of in the deep sea.

5.12 To achieve an adequate measure of reality, it is necessary to use numerical models which are run on a computer. Two very simple models were used in the early assessment. The first predicts the long-term concentrations resulting from steady, continuous release in an idealised ocean. The second estimates the concentrations which could arise if, for example, a current were to carry material in a plume from the disposal site to a fishing ground.

5.13 Models now being developed are still in essence very simple, but are able to provide some description of the shape of the ocean, can incorporate simultaneously all the processes found to be important in different ocean regions, and can be run for a large number of radionuclides with release rates given by the 'waste package model'. The most recent model (see sections 5.14 and 5.15) being developed by MAFF and NRPB and now being used for assessment, incorporates the diffusive processes which disperse and dilute nuclides in the water as well as allowing their removal from the water by adsorption onto particles.

A box model of ocean dispersion

5.14 The dispersion model being developed by MAFF and NRPB* divides the ocean into a number of separate regions or ocean areas. Eight of these are in the Atlantic (see Figure 5.4), geographically separated into two groups east and west of the Mid-Atlantic ridge. Each region is divided vertically into layers or 'boxes' (see Figure 5.5), like a stack of bricks, designed to follow the density surfaces (see section 4.9) along which diffusion occurs most readily. Each box, and there may be as many as 10 in any one region, has its own prescribed temperature and salinity and, subsequently, a concentration of each radionuclide. The upper boxes in each region receive heat and freshwater according to the average values of the ocean's measured supply of heat and precipitation from the atmosphere or the loss due to evaporation. Each box can transfer water, heat and salt into neighbouring boxes, either in adjoining regions (horizontal neighbours, or boxes connected by lines, in Figure 5.5), or in over or under-lying layers (vertical neighbours in Figure 5.5), to simulate mean flows and diffusion consistent with certain physical conservation laws. The transfers are determined by forcing the model to reproduce closely the flow, temperature and salinity distributions directly measured or inferred in the ocean and, once found, can be used to estimate the transfers which would occur when radionuclides are released into the lowest box in the region containing the site (box 24 in Figure 5.5) at rates given by the waste package model.

5.15 In practice the model is further refined. The dump site itself is enclosed within two small boxes to represent the benthic boundary layer

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* A detailed description of this model can be found in the 'Review of the continued suitability of the dumping site for radioactive waste in the North-East Atlantic' prepared for the NEA 1985 Site Review.

Figure 5·4 The Ocean Model: Division into geographical areas

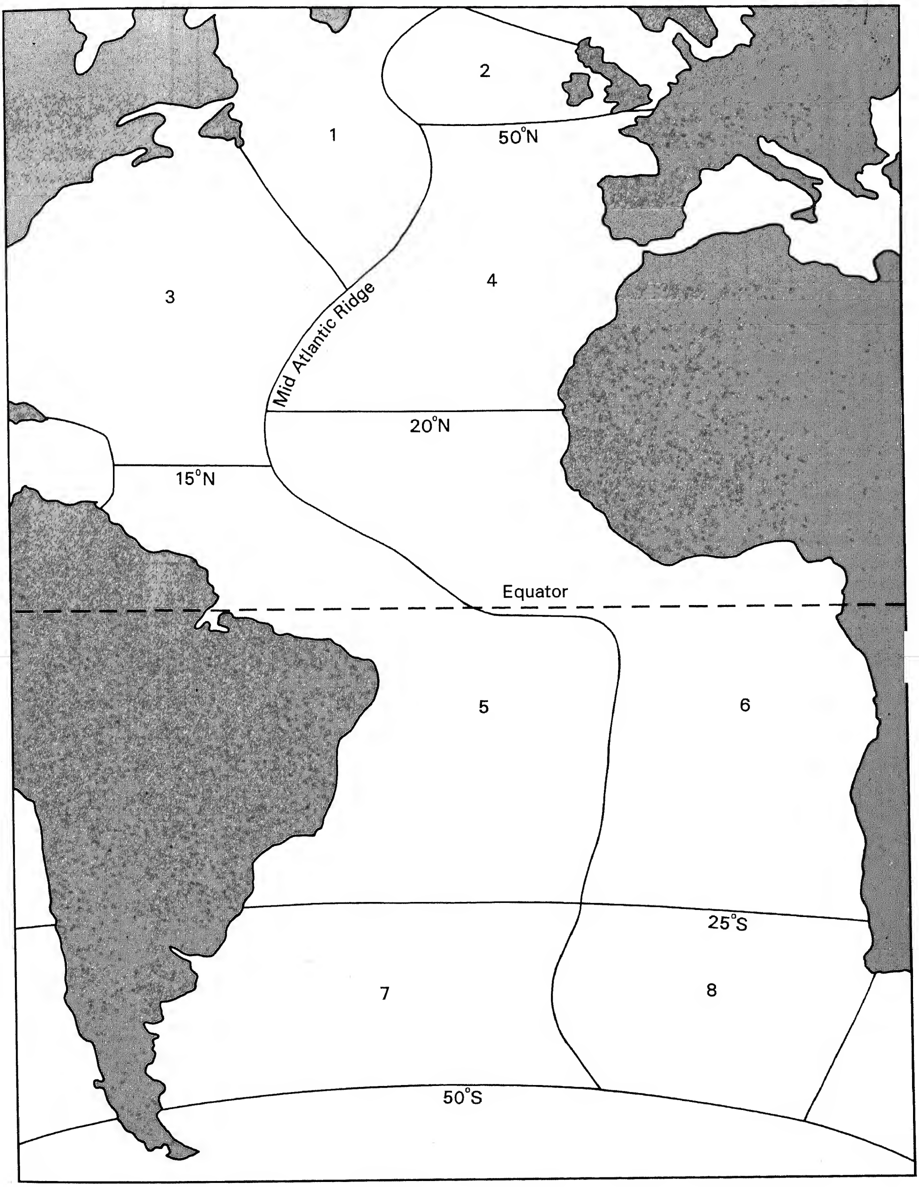
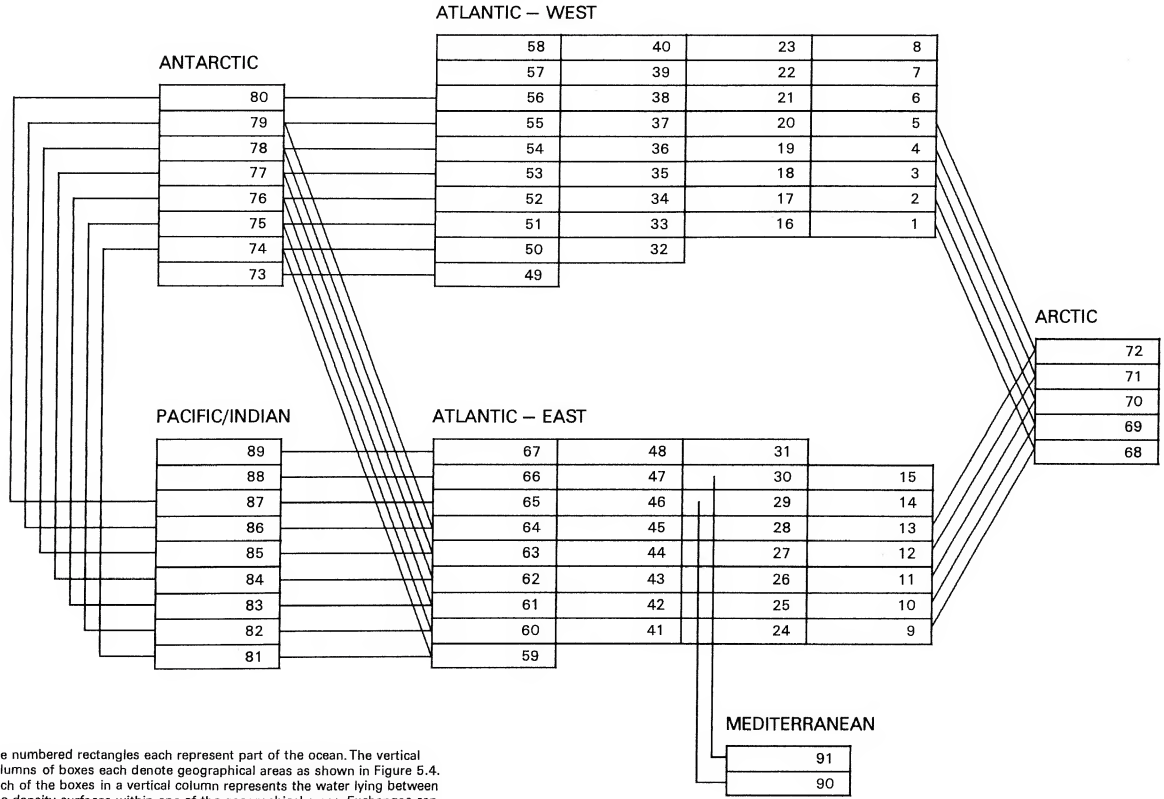


Figure 5·5 The Ocean Model: Box layout



The numbered rectangles each represent part of the ocean. The vertical columns of boxes each denote geographical areas as shown in Figure 5.4. Each of the boxes in a vertical column represents the water lying between two density surfaces within one of the geographical areas. Exchanges can occur between one box and its neighbouring boxes (above, below or to the side), or between boxes in another ocean area which are joined to the first by lines, thus simulating currents and the diffusion of such properties as temperature and salinity, or the movement of radionuclides.

(see section 4.10) and a surrounding region so as to resolve those parts of the ocean where higher-than-average concentrations will occur. The effect of sediments in adsorbing radionuclides is also included. The 'scavenging' of radionuclides from the water by falling particles is simulated by downward transfers between boxes, and additional boxes are included beneath each region to account for transfer to and from bottom sediments by, for example, bioturbation (see section 4.5).

A model of transfer through a food chain

5.16 A biological pathway model through a food chain was described to us by MAFF and is included here as illustration of this type of model. The calculations are based on a hypothetical pathway from contaminated mud on the sea bed at the dump site, to a worm feeding on the mud, and then to an amphipod feeding on the worm; thence to a small squid and (squid often exhibiting cannabilism) to a large squid and then to a surface feeding fish such as tuna, for which there is a commercial fishery (see Figure 5.6). The object of the calculations is to compare the importance of the probability of each link in the food chain feeding exclusively, or only partially, on the preceding contaminated species, with other biological factors, such as the transfer of the nuclide across the gut wall and feeding rates. Information about the fraction of radionuclide which may be adsorbed or assimilated by each species whilst feeding, the weight of food eaten per unit weight of the animals, and the excretion rate, has to be provided from available biological sources principally derived from studies in coastal waters. Figure 5.7 shows some results. The vertical axes show the concentrations of radionuclides in the various components of the model, numbers 1 (the mud), 2 (the worm) to 6 (the tuna). Parts a-c apply to caesium-137 with the same starting concentrations in the mud (100 Bq per kilogram) but assuming different proportions of each animal's food supply comes from the preceding species In (a) each species eats exclusively on the preceding contaminated species the proportions in (b) and (c) are shown in the figure legends. Figure parts (d)-(f) are for plutonium-239 with mud concentrations of 1000 Bq per kilogram. These differ from (a)-(c) both in the assumed proportionate feeding, but principally because the different fraction of radionuclide which can be absorbed in feeding differs. The final concentrations in tuna and squid are very sensitive to the assumed proportions, and hence for example, to the migration behaviour of the various species to and from contaminated areas.

5.17 As more information is obtained about the ocean the models may become more detailed and 'realistic', especially in their representation of processes and topography around the dump site itself.

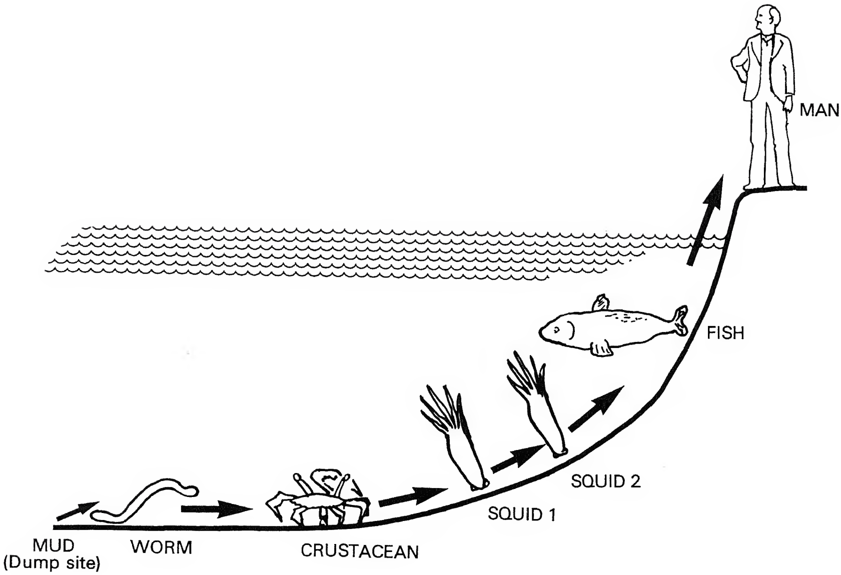
Dose assessment

5.18 The following sections are based on a document kindly prepared for the Review by NRPB.

5.19 The results of the oceanographic dispersion model can be used to calculate the doses to individuals, populations and marine organisms.

5.20 The early estimates were based on the simple ocean models referred to in section 5.12. The most restrictive of the results of these two models were used as input to the dose calculations. In the case of the long term dispersion model, radionuclide concentrations for deep waters rather than the lower values for surface waters, were used to give pessimistic estimates

Figure 5·6 Food chain pathway



(that is overestimates). No account was taken of the probabilities of occurrence of any of the possible short-circuiting processes, and neither of the dispersion models included any allowance for the removal of radionuclides from the ocean by adsorption onto suspended particulates or bottom sediments.

5.21 The doses to individual members of critical groups of the world population were estimated, and then compared to the relevant ICRP dose limit. In calculating doses pessimistic values were taken for factors such as rates of ingestion of sea-food and times of beach occupancy. Both actual exposure pathways (eg consumption of fish, crustacea, molluscs) and hypothetical ones (eg consumption of plankton) were considered. No attempt was made to estimate collective (population) doses or collective dose commitments, because the methodology and models used to calculate individual doses were not appropriate for collective dose estimation. Doses to marine fauna were calculated and it was concluded that the effects on ecosystems would be very small.

5.22 More recent assessments have used the MAFF/NRPB ocean dispersion model described in sections 5.14 and 5.15. Output from the ocean model consists of predicted concentrations of radionuclides in sea water and sediments, as a function of time and space. This information is used to estimate doses to individuals, populations and marine organisms, again as a function of time and space.

5.23 The exposure pathways to man included in the dose assessment model are those in use by IAEA in their work of reviewing the definition of wastes unsuitable for dumping at sea. These pathways are as follows:

★ consumption of surface water fish, mid-depth water fish and deep water fish

★ consumption of seaweed, molluscs, crustacea and plankton

★ consumption of salt and desalinated seawater

★ inhalation of suspended airborne sediments and marine *aerosols*

★ external irradiation during sailing, swimming and spending time on beaches

★ external irradiation as a result of mining manganese nodules from the seabed.

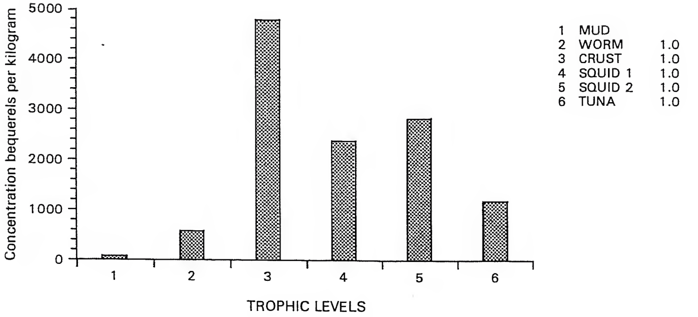
5.24 Some of these pathways are regarded as hypothetical because they do not exist now and are unlikely to exist within the near future.

5.25 Preliminary results of this latest assessment are summarised in Figures 5.8 and 5.9. According to the assumptions made in the model, the highest doses come from the consumption of molluscs, crustacea or weed during the period 85–95 years after the start of dumping. These doses arise from the Arctic Ocean where radionuclides diffusing into the deep water at the dump site are predicted first to reach the surface. Doses from mining occur at the time of peak release (see Figure 5.3) because it is determined from the radionuclide concentrations in the bottom water.

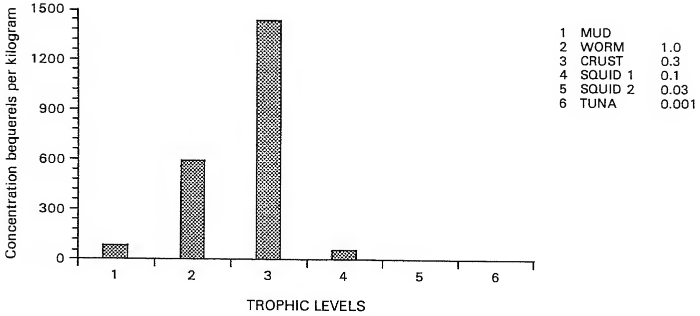
Figure 5·7 The concentration of radionuclides calculated by the biological pathway model

CAESIUM 137

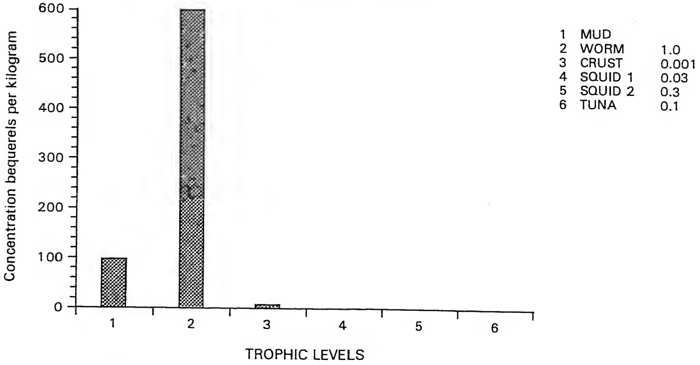
THEORETICAL FOOD CHAIN (a)



THEORETICAL FOOD CHAIN (b)

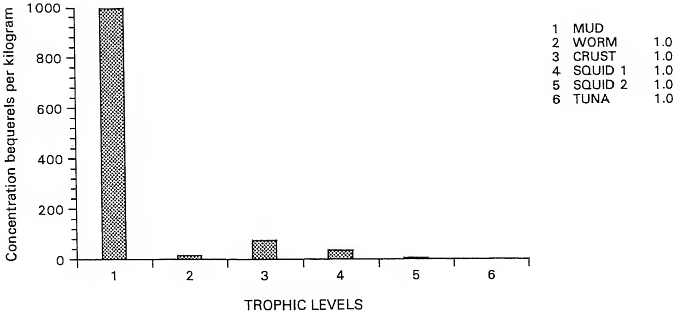


THEORETICAL FOOD CHAIN (c)

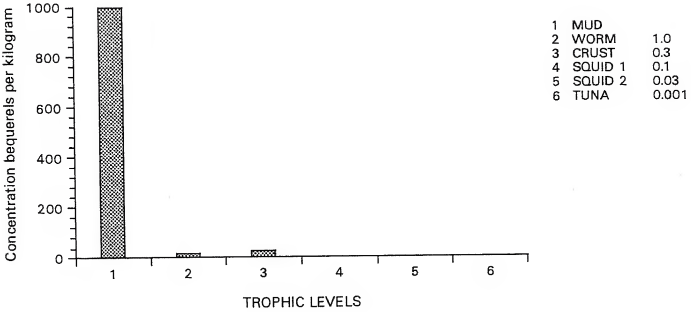


PLUTONIUM 239

THEORETICAL FOOD CHAIN (d)



THEORETICAL FOOD CHAIN (e)



THEORETICAL FOOD CHAIN (f)

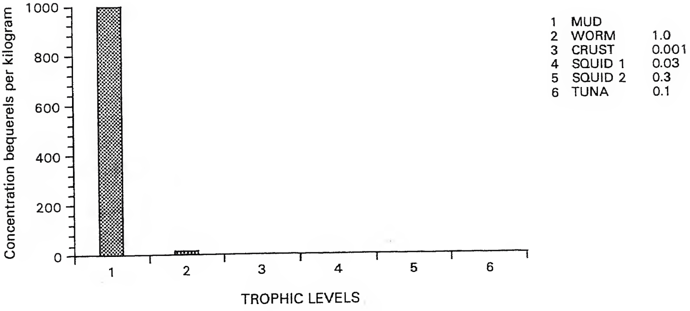


Figure 5.8 Predicted peak annual individual doses from past dumping

Radionuclides	Annual individual dose[1] (μSv)	Exposure pathway[2]	Time of peak dose (years after dumping started)[3]
'Actual' pathways			
Americium-241	0.4	MOLL	85
Plutonium-239	0.01	MOLL, WEED	90
Cobalt-60	0.01	MINE	36
Plutonium-240	0.008	MOLL, WEED	85
Polonium-210	0.006	MOLL, CRUST	95
Plutonium-241	0.005[4]	BEACH	46
Plutonium-238	0.002	MOLL, WEED	67
Caesium-137	0.001	BEACH	60
Sum over all radionuclides and all actual pathways	0.8		
'Hypothetical' pathways			
Plutonium-239	0.008	FISH-D	36
Plutonium-241	0.006		36
Plutonium-240	0.005		33
Americium-241	0.003		41
Caesium-137	0.002		36

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[1] Sum of the external dose equivalent to the whole body of the committed effective dose equivalent from intakes of radionuclides (but see 4). This may be compared with the ICRP dose limit of 5 mSv and the average individual dose due to natural background radiation which is about 2 mSv.

[2] Pathways and sumbols are as follows:

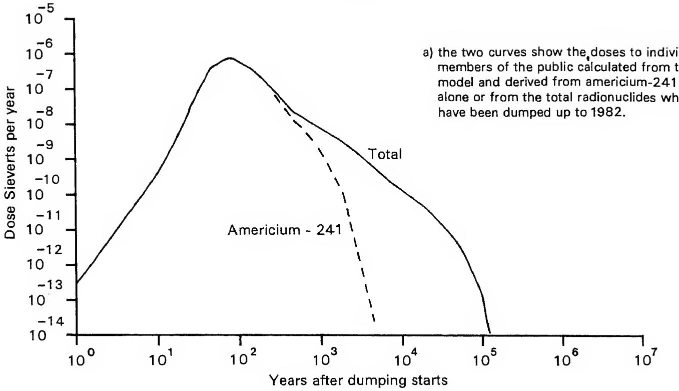
consumption of deep fish (FISH-D); consumption of molluscs, crustacea and seaweed (MOLL, CRUST, WEED); external irradiation from working on the beach (BEACH); deep-sea mining of manganese nodules (MINE).

[3] Dumping in the Northeast Atlantic started in 1949.

[4] Dose to skin from beta radiation.

Figure 5-9 Individual doses from past dumping, (a) actual pathway

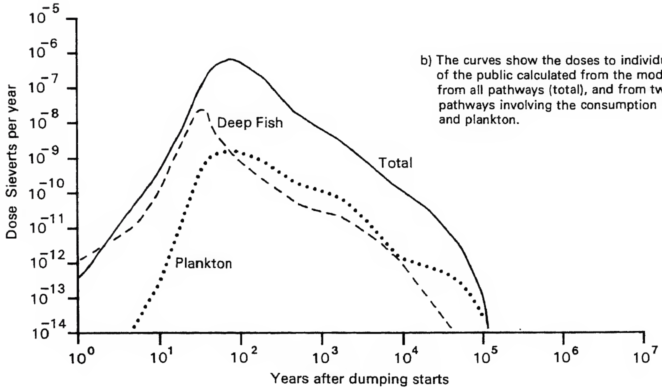
Past



a) the two curves show the doses to individual members of the public calculated from the model and derived from americium-241 alone or from the total radionuclides which have been dumped up to 1982.

(b) actual and hypothetical pathways

Past



b) The curves show the doses to individual members of the public calculated from the model and derived from all pathways (total), and from two hypothetical pathways involving the consumption of deep fish and plankton.

5.26 The maximum dose to an individual member of the public predicted by the model using pessimistic assumptions is 0.8 μSv. At most this would be a very small fraction (about 0.04%) of the annual average dose to individuals in the UK from natural background radiation and about 0.02% of the 5 mSv limit recommended by ICRP (see section 2.25). Calculations were also carried out of doses to marine organisms. These showed that with the exception of small crustacea in the dump site and surrounding area, the additional doses to organisms are less than the lowest level of natural background radiation in the deep sea. The additional doses to small crustacea were calculated to be within the range of natural background variation.

5.27 Following comments from the international group of experts set up by NEA to review the suitability of the dump site, this assessment is being improved and extended. In its final form it will include estimates of collective doses to populations, and a series of sensitivity analyses. It is to be published in 1985.

6. ALTERNATIVES

6.1 We have found it difficult to do justice to considering the implications of sea dumping without being able to give consideration to the alternatives. We were only able to look briefly at these alternatives and how they were assessed.

Land-based alternatives

6.2 There is a requirement implied within the terms of the London Dumping Convention for any particular dumping operation to be justified in relation to land-based alternatives such as shallow land burial. The precise nature of this comparison was not defined at the time of the LDC. In any case, the assessment was left to the national authorities licensing a particular dumping operation.

6.3 So far there has been no serious attempt in the UK to compare sea dumping and land options despite the recommendations of the IAEA for LDC which were first formulated in 1978. Comparisons of this kind are difficult and there has been considerable discussion internationally about methodology – until recently without agreement. The IAEA's formal guidance (Safety Series No 65: Environmental Assessment Methodologies for Sea Dumping of Radioactive Waste) has however just been published. The IAEA recommends that the following factors should be taken into account in comparing sea dumping with land-based alternatives (not necessarily in order of importance):

- ★ Radiological Risk (to workers, public and ecosystems)
- ★ Other Environmental Factors (non radioactive pollutants include with the waste, conventional safety and effects on resources)
- ★ Social and Political Factors (employment, national interests, international concerns, transport, public and political acceptability and nature of legacy to future generations)
- ★ Technical Factors (flexibility and simplicity)
- ★ Financial Cost.

6.4 DOE has indicated that it expects an assessment based on these IAEA recommendations would be undertaken before any future sea disposal operation would be authorised.

6.5 In their second annual report published in July 1984, NIREX set out some proposals for disposal sites on land.

Sea based alternatives

6.6 In addition, a private company, ENSEC Ltd, has proposed that long-lived intermediate level waste be disposed of in the continental shelf in holes drilled from a specially converted oil exploration platform. This might be an alternative for disposal of some wastes that would otherwise be sea dumped. NIREX have contacted a number of organisations, including

ENSEC Ltd to establish what interest there is in progressing this concept. We have been told that even if the ENSEC concept is considered technically feasible and safe, the legal basis of such a disposal method and the political implications are far from clear. The issue of emplacement of radioactive waste in the sea bed is at present unresolved under the London Dumping Convention; the only point of agreement being that the Convention is the appropriate forum for its consideration. In view of these uncertainties, it is not yet possible to say whether emplacement in the continental shelf would prove a viable option or, if so, when it might be implemented.

Storage

6.7 If sea disposal does not resume there will be a need for storage, at least until other disposal facilities are available, that is until the end of the decade or possibly longer. Although there is still some unused storage capacity, NIREX made clear to us that decisions would soon be needed about the development of additional stores.

7. DISCUSSION

Reliability of assessment

7.1 In Chapter 5 we explain how, in assessing the effects of radioactive waste dumping, knowledge derived from several scientific disciplines is used to model and predict the extent and timing of any return of radiation to the human environment and of the impact on the natural environment. Given a relationship between dose and its effect, it is then possible to predict the risk to human health. How reliable is this assessment?

7.2 The reliability of assessment in this complex field depends on several inter-related factors such as:

- the quality of the data upon which the models are based (for example water currents, sediment interactions, biological activity)
- monitoring and validation of predictions drawn from the analysis
- plurality of approach in modelling techniques to minimise errors inherent in individual models.

7.3 The modelling exercise is complex and involves hundreds of man-hours of work which it has been impossible for us to check. The main safeguard lies with the open publication of work in scientific journals and the ensuing debate. There is a general consensus of opinion that the present MAFF/NRPB model overestimates rather than underestimates the risk to an individual.

7.4 There are however several areas in which some uncertainty lies and i which more research is needed, notably:

- the adsorption of radionuclides onto particles and sediment-water interactions
- the physical and biological processes which lead to the dispersal of radioactivity from the site and through the ocean basins.

7.5 All current safety assessments of sea dumping ultimately rely on the system of dose limitation promulgated by the ICRP, and it is common for risk estimation to be expressed solely in terms of ICRP limits, rather than in the more readily understandable terms of numbers of health effects or probabilities of cancer.

7.6 The ICRP system is based on the following principles:

- no practice shall be adopted unless its introduction produces a net positive benefit
- all exposures shall be kept as low as reasonably achievable (the ALARA principle), economic and social factors being taken into account
- the dose equivalent to individuals shall not exceed the limits recommended for the appropriate circumstances by the ICRP.

7.7 In calculating recommended limits, it will be evident that the ICRP cannot use scientific judgements alone, and value judgements are necessary. ICRP has aimed to set a 'permissible' or 'acceptable' upper limit such that the risks to individuals from the radiation hazard are similar or lower than the risks commonly accepted in everyday life. This approach assumes, however, that the practise which gives rise to the risk is commonly 'accepted' and that the health effects are also comparable.

Public acceptability and perceived risk

7.8 The general public acceptability of a risk is in practise often determined by:

- the nature of the hazard; some, such as cancer and genetic damage being greatly feared
- the benefits from the operation that generates the risk
- the degree of personal control in mitigating the hazard (for example careful driving)
- the available alternatives.

Furthermore in relation to nuclear power or nuclear weapons there is:

- distrust of risk estimates
- a 'dread' factor and some considerable ignorance of the nature of the risks
- strongly divided views of the benefit
- differing assessments of alternatives.

Individuals differ greatly both in their 'estimation' and in their 'evaluation' of risks.

Collective doses

7.9 The ICRP have recommended that the collective dose for both present and future generations should be calculated (see section 5.21). These recommendations also add that 'aesthetic' factors would be difficult to quantify but should be taken into account. Some numerical value, for example monetary, should be placed on this net detriment and compared to the cost of abatement. To date no assessments along these lines have been published.

7.10 The system of collective dose assessment also provides a means of comparing different waste management options. Although the LDC has reference to the need to consider land-based alternatives when licensing a sea-dump, referring however only to the 'practical availability' of land sites, the IAEA later (1978) came to define this obligation more closely in terms of radiological safety, by recommending that each licensing authority should justify the sea dumping option with reference to land-based alternatives and make use of collective dose estimates.

7.11 The health consequences of exposure to radiation have been assessed from long term epidemiological studies of atom bomb survivors and from medical practices and are expressed as a risk of cancer-death and death from hereditary diseases. National and international radiological protection bodies estimate the risk of fatal cancer to be about one (possibly as high as three) per 100 for each Sievert, so that at a background level of 1 mSv, an individual would run the risk of 1 in 100,000 of death by cancer. This risk would be spread over the person's lifetime and there being a delay time would be highest several years after the exposure. Similarly for an exposure of one tenth background, as a result for example of an environmental discharge, the additional risk over a person's lifetime, would be one in a million.

7.12 The MAFF/NRPB assessment expects (pessimistically) that some contamination will occur to potential food sources in the Arctic (see section 5.25), but that doses will be in the order of micro-Sieverts, perhaps one tenth of one percent of natural radioactivity in seafood. The risk to an individual would be of the order of one in 100 million. However, no collective dose assessments have been made and the total health detriment is uncertain.

7.13 It should be recognised however that collective dose assessments will not provide all of the answers. Some people may well regard one death, one hundred years hence, as an acceptable price to pay for sea dumping compared to land based alternatives, especially since doses are not certain to occur at the predicted level and may well be smaller. However it may be that the people at risk are members of a distant community deriving no direct benefit from Britain's nuclear programme.

7.14 Ultimately the only way to decide what risks are acceptable is to undertake an assessment using methodologies like those set out by the IAEA and on this basis to reach some consensus in an international forum such as the LDC.

8. CONCLUSIONS

Hazard to health

8.1 There is a general concensus that the present MAFF/NRPB model, which predicts very low impact on human health or upon marine ecosystems, (see section 7.12), may over-estimate rather than under-estimate the risks to man from sea dumping.

8.2 However, we are aware that the safety of dumping cannot be proved to the satisfaction of all concerned except perhaps by the results of a long-term monitoring and assessment programme, the extent and complexity of which cannot at present be formulated.

Present scientific evidence

8.3 The science being undertaken in the UK to examine the environmental effects of sea dumping is of the highest quality. The results are published in the open literature and are openly discussed at international meetings, and this provides some safeguards on the reliability of the work. Clearly the commissioning and general funding of UK research determines in great measure the programmes which are undertaken.

Future dumping

8.4 Since dumping at sea has been effectively suspended since 1982, it is opportune to consider anew the various methods available for the disposal of intermediate and low level waste of different types.

8.5 In 1985 three international reviews are due to be published:

- ★ the Ad Hoc Scientific Review for the LDC (see section 1.8)
- ★ the NEA Site Suitability Review under the OECD Mechanism (see sections 3.4 and 3.6). This will include a collective dose assessment (see section 5.27)
- ★ the Review of the IAEA Definition and Recommendations for the LDC (see section 3.3).

It would be untimely to recommence dumping before these three reviews and a comparison of sea dumping with land based alternatives as recommended by the IAEA (see sections 6.3 and 6.4) have been completed.

8.6 The Fifth and Tenth Reports of the Royal Commission on Environmental Pollution[*] called for studies directed towards establishing the 'Best Practicable Environmental Option' (BPEO) for disposal of each kind of waste. As we have remarked in section 6.3, no serious attempts seem to have been made to compare all the options. We believe that whatever the international requirements it is essential to establish the BPEOs for UK radioactive wastes. The Government should therefore make and publish a comparative assessment of all disposal and storage options as soon as possible.

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[*] The Fifth Report of the Royal Commisssion on Environmental Pollution Cmnd 6371, para 271, 1976.

The Tenth Report of the Royal Commission on Environmental Pollution Cmnd 9149, para 1.23, 1984.

Storage

8.7 It is important that in providing the temporary storage which will be necessary to house the wastes pending disposal, future disposal methods are not prejudiced. We recognise that a cessation of dumping may lead to some problems of land storage in the short-term, but we believe these problems to be surmountable. Early attention will, however, have to be given to the construction of additional storage. Storage may be preferable to immediate disposal if future research will lead to improved understanding of the disposal options available.

Future research and monitoring

8.8 Research into dumping should continue particularly as an aid to the establishment of BPEOs. Several factors used in the modelling require more thorough study, notably the adsorption of radionuclides onto particles and the physical and biological processes of transport (see also section 7.4). We believe that it would be prudent to monitor radioactivity levels in seawater, sediments and marine organisms at appropriately chosen times and places, in the same way that other repositories of toxic wastes are commonly monitored. Valuable lessons might also be learned by studies at dump sites other than the present site.

Public and social factors

8.9 The comparison recommended by the IAEA includes an assessment of public acceptability (see section 7.8). Several major nuclear states have already ceased deep ocean dumping, in some cases as a result of environmental considerations (see section 3.27). The seas are regarded by many as an important source of livelihood, recreation and inspiration, and such people may find ocean dumping offensive and alarming.

8.10 Although there is a body of opinion strongly opposed to ocean disposal of radioactive wastes, there is also strong opposition to alternative strategies of storage or disposal of radioactive waste on land, the more so for people whose immediate neighbourhood is likely to be affected. Where the balance of public acceptability lies is not a matter which we can, or should decide. There is a clear need for surveys and research relating to public perception and acceptability.

8.11 The social and political aspects of dumping cannot be assessed in quite the same objective way as the purely scientific aspects. Much may depend on an individual's understanding of the uses of radionuclides in the UK, and here we recognise a need for more information and open discussion of the issues involves so that the element of 'perceived' risk (see, for example, section 7.8), which plays such a strong emotional part in social attitudes to dumping, can be clarified and the actual risks better appreciated.

8.12 We have found that an important aspect of people's perception of the risks and benefits of waste disposal relates to the origin of the wastes. Wastes that arise from industrial and medical uses of radioactive materials which are seen as benefitting mankind raise fewer issues of concern than those arising from, for example, weapons production. We have been unable to obtain the information necessary to quantify how much of the waste dumped at the Northeast Atlantic dump site falls into these separate categories.

8.13 In our view DOE, assisted by RWMAC, is slowly developing a detailed policy that realistically takes account of both technical requirements and, increasingly, of public opinions and concerns (see section 6.4). This process is not easy. Many would wish that an overall strategy was better determined at this stage, but an independent input into these deliberations is clearly discernible. This report is, we hope, one example.

8.14 The overall responsibility for research into radioactive waste management options lies with DOE, but the expertise in assessing sea dumping lies with MAFF and NRPB (see section 3.12). It would be preferable to have the search for the BPEO for each type of waste developed within a single organisation so that a thorough and integrated study could be made of the merits of different options and where equivalent assessment methodologies could be applied. In this connection we note the development by DOE of independent modelling techniques for land options and these techniques could form the basis for a comparative study of sea and land options.

8.15 Whilst we noticed that Government bodies are expanding support for research in the private sector, particularly on the land options, only a small proportion of the research into deep sea dumping is carried out within non-Governmental organisations. It might help establish public confidence if more independent research were supported either in private industry, or in the universities and research council institutes.

Buoyant materials

8.16 Amongst the miscellaneous items contaminated by radioactivity which are dumped are plastics, notably polythene, which have been shredded before being placed in the drums (see section 3.8). Approximately 25 tonnes were included with the radioactive wastes prepared for disposal in 1983. This material is buoyant, at least in the surface waters, and it is possible that it will remain buoyant at the pressures existing on the ocean floor in the area of the dump site even after the period of time needed for the concrete and steel containing-drums to disintegrate.

8.17 We asked NRPB to make a preliminary assessment of the hazard involved if this material were to float and eventually to return to the sea surface, perhaps to be washed ashore. This showed there to be negligible risk to individuals.

8.18 However such material found cast upon the shore would be objectionable and alarming to many people. The dumping of persistent plastics and other persistent synthetic materials which may float is specifically prohibited in the London Dumping Convention and should therefore not be included with the radioactive wastes dumped at sea.

9. RECOMMENDATIONS

9.1 *We recommend* that the dumping of radioactive waste at the North-east Atlantic dump site is not resumed until the current international reviews and the comparison of sea dumping with land-based alternatives have been completed (see section 8.5).

9.2 *We recommend* that, as a matter of urgency, the Government makes and publishes a comparative assessment of all disposal and storage options with a view to establishing the 'Best Practicable Environmental Options' as called for in the Fifth and Tenth Reports of the Royal Commission on Environmental Pollution (see section 8.6).

9.3 *We recommend* that in storing radioactive waste, producers do not prejudice future disposal or storage options (see section 8.7).

9.4 *We recommend* that a suitable marine monitoring programme should be designed and undertaken and that research should continue as an aid to the evaluation of the Best Practicable Environmental Options (see section 8.8).

9.5 *We recommend* that the search for a BPEO for each type of waste should be developed within a single organisation preferably, in the UK, the DOE (see section 8.14).

9.6 *We recommend* that no persistent plastics or other persistent synthetic materials which may float should be included in any future sea dumping operation (see section 8.16).

APPENDIX

Membership and Secretariat

Chairman	Professor Fred Holliday CBE FRSE Vice Chancellor and Warden University of Durham
Members:	Professor Robert Clark DSc PhD FRSE FLS Department of Zoology University of Newcastle upon Tyne
	Professor Brian Funnell MA PhD School of Environmental Sciences University of East Anglia
	Peter Taylor BA Dip Soc Anth Political Ecology Research Group Ltd Oxford
Scientific Secretariat:	Denise Smythe-Wright PhD Institute of Oceanographic Sciences
	Steve Thorpe PhD Institute of Oceanographic Sciences
Administrative Secretariat:	Stephen Benton Department of the Environment

Organisations and individuals who submitted evidence, opinion and data

British Petroleum
Dr S H Cousins, Open University
Professor Bruce Denness, University of Newcastle upon Tyne
Department of the Environment
Economic and Social Research Council
Greenpeace
The Institution of Professional Civil Servants
International Council of Scientific Unions
The Marine Conservation Society
Ministry of Agriculture, Fisheries and Food
Ministry of Defence
The Ministries of Foreign Affairs in Federal Republic of Germany, France, Japan and the Netherlands
National Radiological Protection Board
National Union of Seamen
Natural Environment Research Council
Nuclear Industry Radioactive Waste Executive
The Royal Commission on Environmental Pollution
The Royal Society
The Trades Union Congress
United Kingdom Atomic Energy Authority

GLOSSARY

Adsorption	The taking up of one substance at the surface of another.
Aerosol	A gas which contains microscopic particles of liquid or solid. For example a cloud.
Biodegradable	Capable of being decomposed by living organisms, for example bacteria.
Biota	A collective term which denotes the plants and animals occurring in a particular region.
Bivalve mollusc	A soft bodied marine animal which has a shell made up of two parts. For example a mussel.
Bq	Becquerel – the standard international unit of radioactivity equal to the number of radioactive disintegrations taking place in a material per second. It equals 27 x 10^{-12} curies.
Cosmic rays	Highly penetrating and energetic rays falling on the earth from outer space.
Crustacea	A class of mainly aquatic animals such as prawns and shrimps.
Dose	The amount of radiation received by a person or a thing exposed to it. The term here is used in a general sense; more often it is qualified, for example, as follows: ● Absorbed dose – the quantity used to measure the energy deposited per unit mass. The unit of absorbed dose is the gray (equal to one joule of energy absorbed per kilogram) ● Dose equivalent – this represents the absorbed dose multiplied by a quality factor which is indicative of the relative biological effect of the radiation. Dose equivalent usually refers to a point in a tissue. It is measured in units called Sieverts (see Sv) ● Collective dose equivalent is a quantity which relates the total exposure of a group of individuals to a particular source of radiation exposure. The collective dose equivalent can be used in cost-benefit analysis for the purpose of justification and optimization; its unit is the man-Sievert. ● Effective dose equivalent acts as an indicator of risk of death from any form of radiation. In calculating the risk death is assumed to result from direct harm to the body or from heridiatry effects in the first two generations.
Fauna	A collective term which denotes the animals occurring in a particular region.
Film badge	Small piece of photographic film used to monitor radiation and dose received. It is normally worn on a lapel, wrist or finger.
Genus	A biological term indicating a category of closely related species of organisms.

Ion exchange resin	A term applied to a variety of materials which have the capacity of taking up, from solutions which are passed through them, any atoms or molecules which have an electric charge. Different varieties of resins are used depending on the nature of the atoms to be exchanged.
Isotope	Atoms of an element which have the same atomic number but different atomic mass. The isotopes of a particular element have identical chemical properties.
Long-lived	Having a long half-life. Some radionuclides have half lives of hundreds or thousands of years, for example americium-243 (half-life = 7.9×10^3 years), potassium-40 (half-life = 1.3×10^9 years).
Modelling	Describing a series of occurrences in a simplified way in order to understand a situation and to predict its effects.
mSv	Millisievert – 1 mSv = 1×10^{-3} Sv (see also Sv).
Radionuclide	Any isotope of an element which is unstable and undergoes natural radioactive decay.
Reprocessing	The term given to recovering and recycling plutonium and uranium from spent fuel.
Short-lived	Having a short half-life. Some radionuclides have half-lives of only a few minutes or days, for example uranium-239 (half-life 23.5 minutes), thorium-234 (half-life 24.1 days). Sometimes radioisotopes with half lives up to 12 or 15 years are included in this category.
Soft	A term which indicates radiation with relatively low energy and consequently little penetrating power.
Sv	Sievert – the standard international unit of dose equivalent, where dose equivalent represents the absorbed dose (in units called grays = 1 joule of energy absorbed per kilogram of tissue) multiplied by a quality factor representing the relative biological effect of the radiation.
TBq	Terabecquerel – 1 TBq = 1×10^{12} Bq (see also Bq).
μSv	Microsievert – 1 μSv = 1×10^{-6} Sv (see also Sv).
Wave period	The time interval between successive waves.

Printed in the UK for HMSO
Dd 738122 C15 11/84